Miscellaneous Paper A-93-1
October 1993

US Army Corps of Engineers
Waterways Experiment Station

Aq'iatic Plant Control Research Program

Relationships Between Fish and Aquatic Plants: A Plan of Study

by K. Jack Killgore, Eric D. Dibble, Jan Jeffrey Hoover
Environmental Laboratory

Approved For Public Release; Distribution Is Unlimited

Prepared for Headquarters, U.S. Army Corps of Engineers

Aquatic Plant Control Research Program

Miscellaneous Paper A-93-1
October 1993

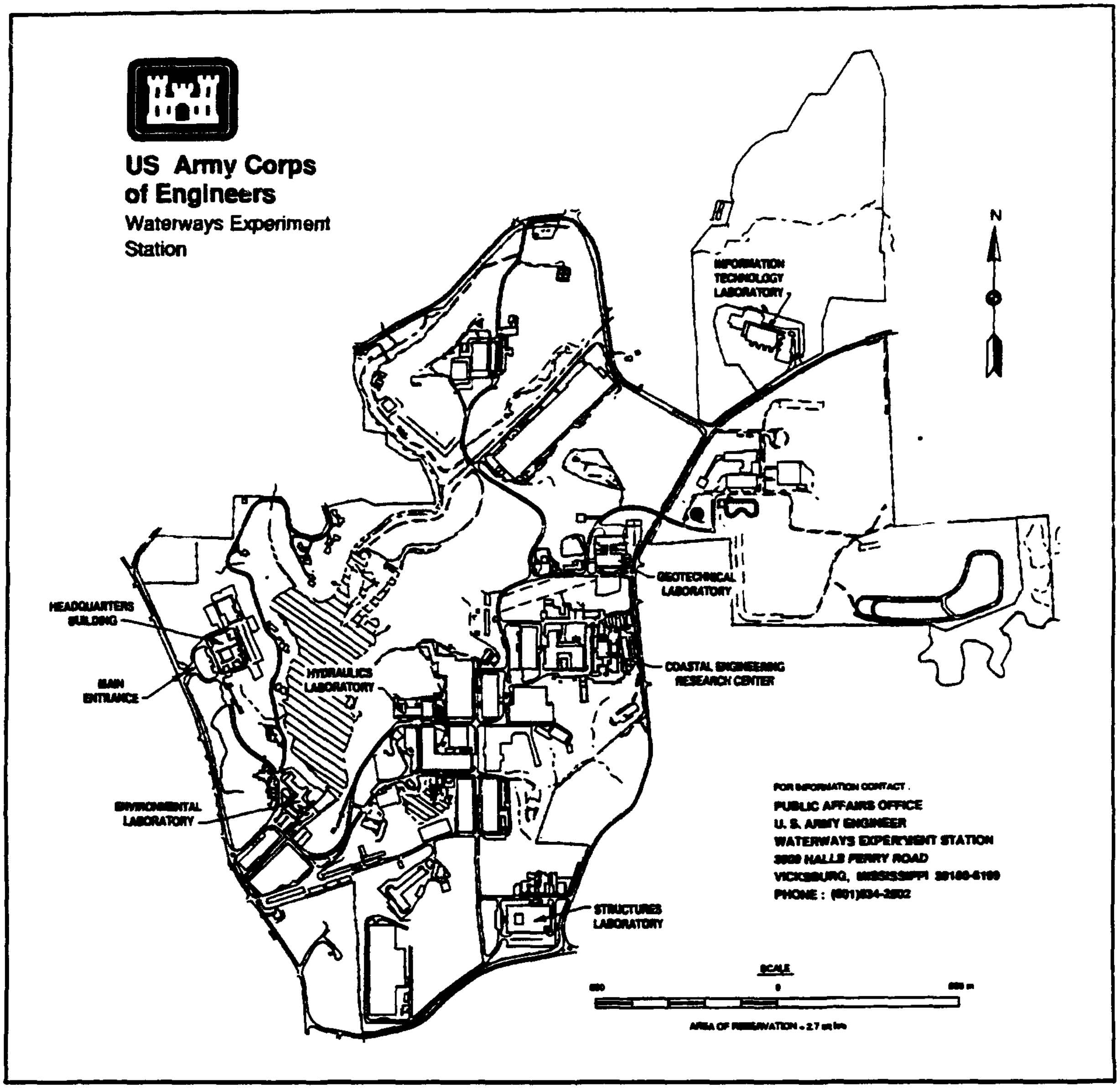
Relationships Between Fish and Aquatic Plants: A Plan of Study

by K. Jack Killgore, Eric D. Dibble, Jan Jeffrey Hoover
Environmental Laboratory

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

Killgore, K. Jack.
Relationships between fish and aquatic plants : a plan of study / by K. Jack Killgore, Eric D. Dibble, Jan Jeffrey Hoover ; prepared for U.S. Army Corps of Engineers.
64 p. : ill. : 28 cm. -- (Miscellaneous paper ; A-93-1)
Includes bibliographical references.
1. Freshwater ecology -- Bibliography. 2. Fish habitat improvement -- Planning. 3. Fishery management. 4. Fishes -- Habitats -- Classification. I. Dibble, Eric D. II. Hoover, Jan Jeffrey. III. United States. Army. Corps of Engineers. IV. U.S. Army Engineer Waterways Experiment Station. V. Aquatic Plant Control Research Program (U.S. Army Engineer Waterways Experiment Station) VI. Title. VII. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; A-93-1.
TA7 W34m no.A-93-1

Contents

Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32806. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3122, Construction General. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for the APCRP. Technical Monitor during this study was Ms. Denise White, HQUSACE.

This report was prepared by Mr. K. Jack Killgore, Mr. Eric D. Dibble, and Dr. Jan Jeffrey Hoover, Aquatic Ecology Branch (AEB), Environmental Resources Division (ERD), EL, WES. Mr. Larry Sanders, AEB, coordinated the workshops. The study was supervised at WES by Dr. Ed Theriot, Chief, AEB, and Dr. Conrad J. Kirby, Chief, ERD. Dr. John Harrison was Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

This report should be cited as follows:

> Killgore, K. J., Dibble, E. D., and Hoover, J. J. 1993. "Relationships between fish and aquatic plants: Plan of study," Miscellaneous Paper A-93-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

1 Introduction and Purpose

The influence of aquatic plants on species composition, abundance, and size of fishes is an important consideration when managing aquatic plants. Numerous studies reviewed in this document show that aquatic plants structure fish populations and influence angler success. The habitat value of plants to fishes and the continuing emphasis on environmental consequences of Corps of Engineers aquatic plant control projects requires that fish/plant interactions be thoroughly understood.

The structural heterogeneity of aquatic plant beds contributes to high numbers of many species of fish that associate with these complex habitats. Sunfishes, for example, have a high affinity to plants and are often the dominant group of fishes in vegetated waters. Many phytophilic fishes are exploitable and, thus, provide an important recreational and commercial resource. As a result, aquatic plants are not only a vital habitat component of aquatic systems but also a source of revenue and recreation for many people.

The interaction between fish and aquatic plants is highly variable, which impedes the formulation of specific fisheries management strategies for vegetated water bodies. This variability is evident on both an ecoregion and a microhabitat scale. Relationships between aquatic plants and fish vary by differences in aquatic systems (river vs. lakes), plant forms (floating vs. submersed), composition of the fish community (sunfishes vs. minnows), and geographic areas (Southern States vs. Pacific Northwest). As a result, the fishery management potential in vegetated habitats is poorly understood.

Questions often arise regarding the amount of aquatic plants necessary to support a viable sport fishery and the relative value of different plant species for spawning, foraging, and predator avoidance by fishes. Competition by water users (e.g., real estate, boating, fishing) confounds this problem. Although there are numerous studies that recommend optimum plant levels to maximize fish production, aquatic plant managers still have problems implementing and justifying control strategies that benefit the fishery. Until functional relationships between plant and fish abundance are determined, the effects of aquatic plant management on fishes will remain subjective and speculative.

The purpose of this document is to describe a plan of study (POS) for fish/plant interactions based on an objective evaluation of the deficiencies in information on fish/plant interactions. The POS will be used to document the need for future research, to serve as a basis for prioritizing and designing studies on fish/plant interactions in different geographic regions of the United States, and to provide documentation for developing a new technology area in the Aquatic Plant Control Research Program (APCRP).

The objectives of this document are to (a) summarize literature on fish/plant interactions, (b) identify specific research areas that address information deficiencies, and (c) describe a POS to quantify relationships between aquatic plants and fish for broad applicability within geographic regions.

2 Literature Review on Fish/Plant Interactions

Introduction

Anthropogenic effects on our nation's aquatic systems are ever increasing the need for controlling plant growth and abundance to maintain viable fisheries. Millions of dollars are spent annually to manage aquatic plants in our nation's rivers, streams, lakes, and reservoirs (Dunst et al. 1974; Koegal, Livermore, and Bruhn 1977; Durocher, Provine, and Kraai 1984), yet little is known about certain ecological interactions between plants and the fish that inhabit them.

Historically, aquatic plants have been an important component in the evolution of freshwater ecosystems (Gray and Taylor 1988). Aquatic plant distribution and abundance continue to be important factors in the ecology of our lakes, streams, rivers, and reservoirs (Wetzel and Hough 1973; Carpenter and Lodge 1986; Hinkle 1986; Kimmel and Groeger 1986; Duarte 1987; Evans et al. 1987; Engel 1988; Boes, Van Ballegoijen, and Uunk 1991). Many of the mechanisms regulating eutrophication in lakes and reserviors are unclear (Phillips et al. 1978); however, submerged plants are a principal component in the process and are often replaced by dense phytoplankton populations (Balls, Moss, and Irvine 1989; Irvine, Moss, and Balls 1989).

Submerged aquatic plants, both exotic and native, serve as contributors of autochthonous organic carbon to lakes, impacting biochemical cycles and productivity in freshwater systems (Goulder 1969; Carpenter and Lodge 1986; Watkins, Shireman, and Haller 1983; Polunin 1984; Scheffer, Achterberg, and Beltman 1984; Duarte 1987, Schramm, Jirka, and Hoyer 1987, Engel 1988, Stevenson 1988; Irvine, Moss, and Balls 1989). In addition, aquatic plant beds decay and supply organic detritus for the aquatic food web (Adams and Prentki 1992, Carpenter and Lodge 1986, Duarte 1986), serve as important substrate and cover for invertebrates (Krecker 1939; Wohlschlag 1950; Pardue 1973; Gilinsky 1984; Morin and Kimball 1984; Whitfield 1984; Lodge 1985; Schramm, Jirka, and Hoyer 1987; Engel 1988; Miller et al. 1989; Chilton and Margraf 1990; Hargeby 1990),

and have important interactive roles with fish (Filmer and Woolcott 1966; Hall, Cooper, and Werner 1970; Werner and Hall 1979; Heck and Thoman 1981; Savino and Stein 1982; Anderson 1984; Mittelbach 1984; Spencer and King 1984; Whitfield 1984; Wiley et al. 1984; Osenberg et al. 1987, Cook and Bergersen 1988, Engel 1988, Rozas and Odum 1988).

The key to effective management of fish and plant populations is thoroughly understanding the relationships between physical habitat (aquatic plants and their impacts) and fish production (critical factors affecting growth, recruitment, and survival). In a practical sense, fishery and aquatic plant managers should look to agriculture for models because agricultural research has gained enough understanding about plant-animal relationships to supply data necessary for successful crop management and pest control programs.

To understand relevant interrelationships between plants and fish, a new approach in the study of aquatic systems is needed. Researchers must first define and then classify fish habitat created by aquatic plants; develop innovative, precise, and accurate sampling schemes; identify and understand the function of these habitats; develop modified management plans incorporating the information collected; and finally, but probably most importantly, initiate an interdisciplinary exchange of data and cooperation between fishery biologists, aquatic plant managers, aquatic ecologists, botanists, and limnologists.

The intent of this study was to review previous studies on aquatic fish/plant interactions and provide the biologist with basic information that can determine availability of critical habitat and factors that impact growth, recruitment, and survival of fish populations.

Classification of Aquatic Plant Habitats

Fish habitat is classified at regional system (macro) and local (micro) levels (Table 1). Each type of classification makes assumptions about factors that structure fish communities. There are, however, many issues that confound classification schemes. Habitat is a multivariate combination of discrete levels of environmental variables (Baker, Killgore, and Kasul 1991). Emphasis of particular variables is usually subjective, and the many factors that determine species composition and distribution of aquatic plants are vague and difficult to predict. Macrophyte growth, composition, and distribution are frequently dependent on limiting factors in the chemical composition of sediments and water (Barko et al. 1982, 1984, Barko, Adams, and Clesceri 1986; Langeland, Linda, and Haller 1985; Sutton 1990), and to a lesser extent, elevation, morphometry of the water body, and substrate particle diameter (Jackson and Charles 1988). In addition, water transparency, depth, and chlorophyll *a* concentrations tend to be associated with macrophyte abundance (Canfield, Maceina, and Shireman 1983, 1984).

Fish assemblages and their habitat have been delineated successfully by a regional classification, i.e., stream and river drainage systems (Hocutt and Wiley 1986; Rohm, Giese, and Bennett 1987; Lyons 1989). This type of regional classification has been greatly improved using Geographic Information Systems (GIS). A recent effort, called E-Map, is an example of using the GIS to delineate fish habitat on a regional scale allowing approximately 800 lake and stream sites to be evaluated annually[1] (Whittier and Paulsen 1992). An excellent source of information on regional distribution of fishes is "Zoogeography of North American Freshwater Fishes" by C. H. Hocutt and E. O. Wiley (1986); this document provides specific distributional data by region and drainage basins and discusses reasons why a particular community structure has formed within that region.

Classification at the system level includes characterizing relative abundance and distribution of emergent, floating-leaved, and submersed plants in lake littoral zones from aerial photography (Canfield et al. 1990), and using plant biomass to delineate differences in aquatic plant habitats (Maceina et al. 1984; Duarte 1987; Hoover, Killgore, and Morgan 1988; Pine, Anderson, and Hung 1989, 1990; Sliger et al. 1990). Attempts to quantify phytoplankton at the systems level are more common than quantifying macrophyte beds because the latter have patchy distribution within a lake, and the biomass within patches is highly variable (Downing and Anderson 1985).

The classification of stream substrate described by Bain, Finn, and Booke (1985b) is one approach for habitat analysis at the microlevel, and similar studies are needed in classifying important spatial parameters in aquatic plants. Although past research focused on differences between structured versus nonstructured or vegetated versus nonvegetated habitats (Werner et al. 1977; Watkins, Shireman, and Haller 1983; Mittelbach 1984; Gregory and Powles 1985; Layzer and Clady 1987; Paller 1987; Cook and Bergersen 1988; Hoover, Killgore, and Morgan 1988; Morgan, Killgore, and Douglas 1988; Miller et al. 1989; Todd and Rabeni 1989), others have made an attempt to quantify additional parameters at the micro level and determine their importance to fish (Table A1).

Plant microhabitats have been delineated by measurements of plant stratification in the form of canopy, midcanopy, and lower stem strata (Morin and Kimball 1984, Whitfield 1984, Engel 1988); stem and plant densities (Savino and Stein 1982, Anderson 1984, Downing and Anderson 1985); taxa; and differences in emergent versus submergent (Scheffer, Achterberg, and Beltman 1984; Durocher, Provine, and Kraai 1984; Holland and Huston 1984; Whitfield 1984; Lodge 1985; Schramm, Jirka, and Hoyer 1987; Engel 1988; Hoover, Killgore, and Morgan 1988; Nichols, Schloesser, and Geis 1988; Miller et al. 1989; Canfield et al. 1990).

---

1 Personal communication, 1992, F. H. McCormick, U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring Systems laboratory, Cincinnati, OH.

Shade created by dense structure ' ıs been quantified and may be important to fish by allowing better visibility in foraging and predator avoidance (Helfman 1979,1981). However, in other investigations, shade was measured and did not appear to affect habitat preferences by bass or bluegills (Lynch and Johnson 1989). Even the size of interstitial spaces in aquatic structures has been measured to evaluate the value of important fish habitat (Johnson, Beaumier, and Lynch 1988; Lynch and Johnson 1989; Walters, Lynch, and Johnson 1991). These studies show the use of structural habitat by largemouth bass is correlated with body size; smaller fish (<300 mm total length (TL)) used smaller (40 or 350 mm) interstitial spaces than did larger (>300 mm TL) fish.

Fish Distribution, Diversity, and Abundance

Fishes that inhabit aquatic plant habitats

Based on data collected from radiotelemetry and other types of fish movement studies, many fish prefer and inhabit areas of aquatic plants that provide complex structure. Submersed vegetation in a Colorado reservoir was preferred by northern pike (*Esox lucius*) and was the key factor in their distribution and habitat use (Cook and Bergersen 1988). Young-of-year (YOY) northern pike also prefer submerged vegetation over emergent vegetation and sho ed a tenfold increase in preference for vegetated areas over nonvegetated areas (Holland and Huston 1984). The strong preference for aquatic plant habitats by northern pike appeared not to be related to food, and the overall production of the YOY pike was best in these areas (Holland and Huston 1984).

Brown bullheads (*Ictalurus nebulosus*), banded killifish (*Fundulus diaphanus*), pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), and yellow perch (*Perca flavescens*) have been sampled in heavily vegetated sites (Killgore, Morgan, and Rybicki 1989). Representative species from the Percidae, Cyprinidae, Cyprinodontidae, and Centrarchidae families prefer complex, species-rich, macrophyte beds over lesser complex and depopurate beds (Poe et al. 1986). Janecek (1988) provides an excellent summary of fishes inhabiting vegetated areas in the Upper Mississippi River System.

Larval fish abundance and species composition is much higher in macrophyte beds than in open water (Floyd, Hoyt, and Timbrook 1984; Paller 1987). Some work on the drift of larval fish in streams and rivers has been conducted (Floyd, Hoyt, and Timbrook 1984, Armstrong and Brown 1983), yet relatively little is known about freshwater fish larvae in littoral areas of lakes and reservoirs. Difficulty in sampling these habitats is a contributing factor to lack of study.

Effects of plant density on fish abundance

Evaluation of aquatic plant control programs has provided aquatic biologists system-scaled experiments on the gross effects that plant removal has on fish populations. Therefore, much of the available literature on fish abundance in association to plants is related to plant control studies (Prowse 1971; Strange, Berry, and Schreck 1975; Terrell 1975; Terrell and Terrell 1975; Ware et al. 1976; Bailey 1978; Colle, Shireman, and Rottman 1978; Lembi et al. 1978; Mitzner 1978; Rottmann and Anderson 1978; Haller, Shireman, and DuRant 1980; Shireman and Maceina 1981; Savino, Stein, and Marschall 1985; Bettoli, Morris, and Noble 1991).

Plant density is important in determining species composition and abundance of fishes. High fish densities (15,000 to 98,000/ha) have been estimated from collections made in intermediate densities of vegetated areas (Barnett and Schneider 1974; Borawa et al. 1978; Shireman, Colle, and DuRant 1981; Killgore, Morgan, and Rybicki 1989), and as plant density increases, aquatic plant beds support higher numbers of smaller fish (Barnett and Scheider 1974). Experiments in controlled environments suggest that intermediate plant densities maximize foraging success by largemouth bass (Anderson 1984). Many investigators suggest that moderate levels (10 to 40 percent coverage) of plant density are optimal for fish production, commercial fishing, and for stabilizing water quality in freshwater systems (Hestand and Carter 1978; Crowder and Cooper 1979a, 1979b; Wiley et al. 1984). Janecek (1988) summarized suggested optimal vegetative levels for selected Upper Mississippi River fishes (Table 2).

Sunfish (*Lepomis* spp., *Pomoxis* spp.) populations increase with aquatic plant abundance (Ware and Gasaway 1977; Shireman, Colle, and DuRant 1981) and decrease in number with a reduction in plant coverage (Forester and Lawrence 1978, Noble 1981), sometimes immediately (Borawa et al. 1978). Likewise, largemouth bass (*Micropterus salmoides*) production increases with an increase of aquatic plant abundance (Borawa et al. 1978; Moxley and Langford 1982; Durocher, Provine, and Kraai 1984) and decreases with reduction in plant abundance (Ware and Gasaway 1976). Natural senescence in aquatic macrophytes decreases abundance of fishes due to the reduction of invertebrates (Whitfield 1984). Even reductions of plant communites due to boat disturbance can decrease species composition and abundance (Murphy and Eaton 1981). Juvenile largemouth bass inhabit vegetated areas (Barnett and Schneider 1974, Moxley and Langford 1982), and there appears to be a significant relationship between YOY largemouth bass survival and recruitment, and the availability of submerged vegetation (Aggus and Elliot 1975; Haller and Sutton 1975; Shireman et al. 1984).

Removal of plants in aquatic systems also affects abundance of pelagic species. Reduction of aquatic plants increased numbers of shad (Bailey 1978, Maceina and Shireman 1985); the increase of plant abundance has been shown to decrease standing crops of shad (Noble 1981). Usually, as macrophytes increase, the plant mass shifts primary productivity at the

expense of phytoplankton and reduces food resources available to planktonic feeders (Sills 1964, Prowse 1971, Wiley et al. 1984, Noble 1986).

The effects of plants on catfish are inconclusive. Wiley et al. (1984) and Noble (1981) showed increases in the number, recruitment, and survival of catfish after plants were removed with grass carp. However, Borawa et al. (1978) reported the opposite trend. Even though data supplied from plant removal literature is extensive, care must be taken in reaching conclusions on plant effects on fish. Since most field investigations only indirectly address the mechanisms regulating fish/plant interactions, many of the results from this literature are inconclusive and contradictory (Evans et al. 1987). For example, most data suggest that plant removal has major impacts on fish populations. Other studies suggest that plant reduction has little effect on fish populations and that factors other than aquatic plants may have greater impact (Bailey 1978, Noble 1986). Unfortunately, few long-term studies on fish populations before and after removal of aquatic plants have been conducted (Bettoli, Noble, and Betsill 1992).

Functional Uses of Aquatic Plants By Fishes

Importance of understanding microdistribution

Functional (behavioral) response of an organism to its habitat determines its niche and its relationship to the environment. Understanding the mechanisms that regulate distribution and habitat choice in fish is essential to determining reasons why fish utilize aquatic plant habitats. Observed phenotypic differences of fish among microhabitats indicate that individual fish specialize on one habitat (Layzer and Clady 1987, Rosenzweig 1991). Previous works have demonstrated some general distribution patterns and habitat partitioning by fish (Werner et al. 1977, Gorman and Karr 1978, Hubert and Lackey 1980, Mittelbach 1984, Probst et al. 1984, Martin-Bergmann and Gee 1985, Pringle et al. 1988, and Todd and Rabeni 1989). Recently, the role of learning in fish behavior has been addressed in the literature (Kieffer and Colgan 1992), suggesting fish learn to choose specific habitats to improve foraging and predator avoidance (Milinski and Heller 1978; Ehlinger 1989; Colgan, Gotceitas, and Frame 1991; Kieffer and Colgan 1991).

Unfortunately, specific behavioral data needed to determine the causal mechanisms regulating habitat use by fish and important interactions between fish and their habitats are sparse (Howick and O'Brien 1983, Kieffer and Colgan 1992). However, explanations have been presented which state why fish may use the complex habitats located in aquatic plant beds. Fish may use plant habitat to avoid predators (Hall and Werner 1977; Laughlin and Werner 1980; Power, Mathews, and Stewart 1985; Mittelbach and Chesson 1987; Schmitt and Holbrook 1985), to forage on

epifauna (Werner et al. 1977; Laughlin and Werner 1980; Devries, Stein, and Chesson 1989), to improve visual acuity of environment with the shade created by plant canopies (which may help both foraging and predator avoidance behaviors) (Helfman 1979, 1981; Diehl 1988), and to create optimal spawning and nesting sites (Tester 1930, Vogele and Rainwater 1975, Mesing and Wicker 1986, Quinn and Dittman 1990, Hoff 1990).

Plant habitats and food

Aquatic plants supply structurally complex habitat (Engel 1983, 1984, 1985) and increase nutrients for the food web that promote increased diversity and stability in macroinvertebrate and aquatic faunas (Rosine 1955; Boyd 1971; Stenseth 1980; Watkins, Shireman, and Haller 1983, Engel 1984; Schramm, Jirka, and Hoyer 1987). Epiphytic algae on plants increase productivity and cover in littoral areas. Plants affect environmental conditions of water by resistence of mixing and gradients in dissolved oxygen (DO), pH, and temperature form in and around plant beds, which fluctuate differently than in open areas (Van, Haller, and Garrard 1978; Bowes, Holaday, and Haller 1979).

Aquatic plants supply important habitats containing food resources for both juvenile and adult fish. Leaves and stems of aquatic plants provide support and cover for macroinvertebrates (Pardue 1973; Pardue and Nielsen 1979; Keast 1984; Engel 1985; Goldsborough and Robinson 1985; Beckett, Aartila, and Miller 1992), and plant beds supply additional nutrients to support a diverse group of benthic macroinvertebrates (Scott and Osborne 1981, Gilinsky 1984, Miller et al. 1989). The spatially complex habitats of aquatic plant beds contain about twice as many macroinvertebrates as nonvegetated areas (Gerking 1957). The reported high abundances of macroinvertebrates on and below macrophyte beds (Andrew and Hasler 1943; Rosine 1955; Quade 1969; Watkins, Shireman, and Haller 1983; Morin and Kimball 1984; Scheffer, Achterberg, and Beltman 1984; Engel 1985; Lodge 1985; Schramm, Jirka, and Hoyer 1987; Hanson 1990) may serve as potential forage bases for smaller and younger fishes. Many fish feed on the macroinvertebrates present in aquatic plant habitats (Flemer and Woolcott 1966; Keast 1985a, 1985b; Hoover, Killgore, and Morgan 1988). The distribution of microinvertebrate populations is site specific; they inhabit only particular aquatic plant species (Scheffer, Achterberg, and Beltman 1984; Hargeby 1990). Habitat-associated differences in the diet of fish frequently reflect this distribution (Keast and Webb 1966; Keast 1985a; Hoover, Killgore, and Morgan 1988; Layzer and Clady 1991).

Availability of cover and predation effects

Predators are important in structuring aquatic communites (Hall, Cooper, and Werner 1970; Connell 1975; Hall et al. 1979, Power, Mathews, and Stewart 1985; Sih 1987; Hunter and Price 1992, Power 1992).

Size-dependent predation operates in littoral areas of freshwater systems, and the structurally complex habitats provided by plants can reduce predator risk for prey (Keast 1985a; Charnov, Orians, and Hyatt 1976; Werner et al. 1977, 1979; Werner, Hall, and Werner 1978; Reynolds and Eaton 1983; Gilinsky 1984; Werner and Gilliam 1984; Mittelbach and Chesson 1987). Prey fishes may avoid predators by using plants as interference and refuge. The spatial distribution of prey organisms in relation to refuge and a predator may be either chance (Huffaker 1958) or may be a behavioral response by the prey to choose a habitat (Giles and Zamora 1973; Ware 1973; Charnov, Orians, and Hyatt 1976; Stein and Magnuson 1976, Stein 1977). Predators maximize energy gain by selecting optimal food items (Anderson 1984), and prey minimize predator risk (mortality) by modifying microdistribution and behavior in the presence of a predator (Stein 1977, Wildhaber and Crowder 1991).

Aquatic plants are important to fish because their structures supply cover from predators and habitat for food resources. Moderate densities of plants increase habitat heterogeneity, which influences community stability (Stenseth 1980) and determines the extent of interactions between fish and their prey (Glass 1971; Smith 1972; Murdoch and Oaten 1975; Crowder and Cooper 1979a, 1979b, 1982; Saiki and Tash 1979; Savino and Stein 1982; Gilinsky 1984; Johnson, Beaumier, and Lynch 1988). Aquatic vegetation densities, spatial configuration, and growth forms can affect prey vulnerability to predation (Watkins, Shireman, and Haller 1983). Yet, fish-foraging probability is significantly enhanced by feeding in the submerged aquatic vegetation. The same plant beds not only afford protection from predators but also can provide a rich foraging habitat (Rozas and Odum 1988). Seasonal variation in the growth of exotic plants may be important by increasing forage and refuge habitat for juvenile fish populations in late fall and winter when native macrophytes are seasonally absent (Nichols, Schloesser, and Geis 1988). Too much structure or too many plants can reduce interactions between fish and prey, leading to a reduction of fish production (Dunst et al. 1974, Smith and Crumption 1977, Diehl 1988). An intermediate level of plant density and structure appears optimal (Killgore, Morgan, and Rybicki 1989; Glass 1971; Savino and Stein 1982; Crowder and Cooper 1979a; Colle and Shireman 1980).

Aquatic plant beds serve as protective habitats for macroinvertebrates and other fish prey species. Because of their spatial complexity in providing refugia, aquatic plant beds decrease predation effects, thus increasing both species richness and density of most macroinvertebrates (Gilinsky 1984). The total macroinvertebrate biomass and abundance is unaffected by differences in fish biomass (Hanson and Leggett 1986). However, high fish densities forced into refuge habitats by predators can precipitate fierce forage competition for resources and significantly reduce invertebrate size and abundance (Mittelbach 1981, 1988).

Plant habitats and factors affecting growth

Vegetation in aquatic systems impacts growth and condition in fish. Based on a survey of 300 systems, growth of largemouth bass decreased as vegetation abundance increased (Engel 1985). Others have reported similar results in the relationship of increased plant abundance and the growth rates of largemouth bass (Colle and Shireman 1980, Noble 1986, Maceina et al. 1991). The opposite appears to be true in the growth and condition of smaller centrarchids. Since bluegill and other small centrarchids use vegetation as a food source (Gerking 1962, Engel 1988), the increase of vegetation tends to increase growth rates and conditions in bluegill, crappie, and redear sunfish populations (DiCostanzo 1957; Bailey 1978; Colle and Shireman 1980; Wiley et al. 1984; Maceina and Shireman 1985; Savino, Marschall, and Stein 1992). The decrease or lack of vegetation is correlated with reduced size (Evans et al. 1987). Too much vegetation can actually decrease growth rates in these fish (Colle and Shireman 1980, Shireman et al. 1984, Colle et al. 1986), but control of plant densities can maintain optimal growth and condition (Cope et al. 1970).

The availability of plants and the structure they provide may affect growth rates by altering foraging behaviors in both prey and predatory fish. The exposure to predators strongly determines smaller and younger fish's feeding behaviors, which affect foraging rates (Ware 1973), and the amount of exposure to a predator is directly related to structural habitat availability and its complexity (Smith 1961; Macon 1966; Danehy, Ringler, and Gannon 1991).

The use by juvenile and smaller prey fishes of such habitats to avoid predation can increase foraging competition (Goldberg and Barton 1992), thus reducing food intake and retarding growth (Mittelbach 1988). The size that younger fish reach in their first year of growth is critical for overwinter survival (Gutreuter and Anderson 1985), which influences fish recruitment and production.

Larger, predatory fishes' growth and condition also may be influenced by aquatic plants. Habitat complexity caused by aquatic plant abundance regulates piscivory in the littoral zone of lakes (Bettoli, Noble, and Betsill 1992). Prey-capture rates tend to decline monotonically with an increase of structural complexity (Crowder and Cooper 1979a), and foraging efficiency by predatory fish decline as the habitat becomes more spatially complex (Glass 1971, Stein and Magnuson 1976, Vince et al. 1976, Van Dolah 1978, Cooper and Crowder 1979, Saiki and Tash 1979, Heck and Thoman 1981, Savino and Stein 1982, Johnson, Beaumier, and Lynch 1988).

For bass and other large predators, the increases in visual barriers provided by plant stems may decrease foraging success (Savino and Stein 1982) by increasing search, handling times, and swimming velocities but reducing encounter, attack, and capture rates (Glass 1971, Crowder and

Cooper 1979b, Anderson 1984). Thus, in high densities of aquatic plants with additional spatial complexity, larger fish may expend more energy in searching and capturing prey items, and less successful captures. This may result in a loss of caloric intake normally allocated towards growth or reproduction. However, largemouth bass may modify their foraging tactics from actively pursuing prey to ambushing them, thus minimizing energy costs required for prey capture (Savino and Stein 1982; Killgore, Morgan, and Rybicki 1989).

Reproduction and survival of larval fish

Much of the data on spawning success comes from studies conducted on largemouth and smallmouth bass, as well as other centrarchids. Bass and sunfish select nesting sites that are protected from wave action (Tester 1930, Kramer and Smith 1962, Miller and Kramer 1971, Summerfelt 1975) and keep their immediate nest sites cleared of vegetation (Tester 1930, Hubbs and Bailey 1938, Watson 1955, Latta 1963, Mraz 1964, Summerfelt 1975), yet they choose nest sites with some type of vegetation or complex structure nearby (Tester 1930, Vogele and Rainwater 1975, Carpenter and McCreary 1985, Messing and Wicker 1986). However, too much vegetation can hinder spawning adults by decreasing availability of nest sites (Colle and Shireman 1980).

Correlation of nesting success and recruitment with years of high water was observed (Hulsey 1959, Von Geldern 1971, Meals and Miranda 1991), suggesting that inundated vegetation supplies optimal areas for nesting and important cover for survival of larval and juvenile fishes. Nesting success is improved by increasing the available complex structure that spawning fish use for protection (Vogele and Rainwater 1975, Johnson and Bagwell 1979, Hoff 1990), and the increase of submerged vegetation in areas lacking other types of structure, i.e., timber or coarse substrate, may improve survival of larval fish and the year's recruitment (Kramer and Smith 1962; Bryant and Houser 1971; Miranda, Shelton, and Bryce 1984; Meals and Miranda 1991).

Few studies directly address habitat use by larval and juvenile fish, but data do suggest aquatic plant beds provide complex structure needed for larval fish to avoid predation (Aggus and Elliot 1975) and can serve as important nurseries for larval fish (Gregory and Powles 1985). Light traps showed that early life stages of darters and pumpkinseed sunfish selected shallow, macrophyte-dense areas; perch demonstrated an early ontogenetic shift in these habitats. The prolarvae preferred shallow, high-density macrophyte areas while postlarvae preferred deep, low-density macropohyte zones (Gregory and Powles 1985).

Sampling Strategies

Quantification of fish/plant relations

Before effective management strategies can be put into practice, information is needed on the earlier life stages of fish, the behavior of fish, and their interaction with their habitat. Fisheries management has focussed on harvestable fish and neglected interactions between behavior of small fish and their environment. In the past, fishery management not only lacked empirical data to support sound management practices but also lacked sampling methods to properly assess the questions related to fish/plant interactions. The fundamental reason for a lack of data on important fish/plant interaction is the difficulty in sampling and measuring fish in aquatic plants (Gregory and Powles 1985). New and innovative sampling methods are required in furthering the understanding of their relationships. A number of studies have successfully used a variety of sampling techniques for quantifying fish and their habitat in aquatic vegetation (Table 3).

Measuring plants and microfauna

Both direct and indirect methods have been used to sample plant species and composition of their macroinvertebrate fauna. Some of the direct techniques include using modified dredges for sampling and estimating plant biomass in littoral habitats (Sliger et al. 1990) and by manually clipping sections of plant stems (Gerking 1957). Gerking (1957) suggested differences of benthic marcofauna and phytomacrofauna can be distinguished by collecting plant sections near the substrate and separating them from samples located higher on the plant stem.

Where water conditions are favorable, samples have been directly taken by divers either with the aid of SCUBA or snorkel gear. Transect and quadrat sampling has been successfully conducted by divers to sample submerged vegetation and the macroinvertebrate fauna that inhabit them (Kautsky, Widbom, and Wulff 1981; Pringle 1984; Machena and Kautsky 1988). These methods have proved to be the most precise and efficient way of sampling biomass and estimating standing crop of macrophytes (Downing and Anderson 1985).

Duarte (1987) suggests that sampling aquatic vegetation with divers is time-consuming and cumbersome; alternatively, indirect methods such as the use of a fathometer for sampling aquatic vegetation may be more efficient (Maceina and Shireman 1980; Maceina et al. 1984; Duarte 1987; Pine, Anderson, and Hung 1989). Biomass sampling has been used to define differences in plant distribution, abundance, and species composition (Forsberg 1959; Edwards and Moore 1975; Cassani and Caton 1985; Smart and Barko 1988). An indirect estimation of biomass with echosounder tracings may serve as a good tool for quantifying effects of plant management operations (Pine, Anderson, and Hung 1989). In addition, the

use of aerial videography (Lukens 1967) as a remote sensing tool and of automated positioning systems (Harvey, Patterson, Pickett 1988) serves as a promising approach in quantifying macrophytes at the system level (Jennings, Dewey, and Voh 1991).

Measuring fish in plant habitats

Shallow, structurally complex plant habitats are often primary spawning and nursery grounds for fish, and since these habitats are very difficult to sample, more attention is needed on sampling methods. Under suitable conditions, a diver team can rapidly census fish populations and measure species composition and abundance in habitats that are impossible to sample with traditional methods (Northcote and Wilkie 1963, Keast and Harker 1977, Dibble 1991). Divers with cameras have been used to quantify salmon populations (Ellis 1961). The relative abundance of littoral zone species can be efficiently determined along shoreline microhabitats in rivers, lakes, and reservoirs (Goldstein 1978, Slaney and Martin 1987, Zubik and Fraley 1988, Dibble 1991). However, in conditions where fish are selecting the most dense cover, visual methods by divers may be hindered (Heggenes, Brabrand, and Saltveit 1990).

Modified electroshocking equipment has been devised to sample specific microhabitats (Bain, Finn, and Booke 1985b). This sampling method is effective for site-specific sampling, yet it was designed for systems without high densities of vegetation. However, with slight innovation such equipment may be applicable for precise and accurate sampling of fish in dense vegetation (Dewey, Holland-Bartels, and Zigler 1989; Dewey 1991). In addition, this technique avoids sampling biases that typically prevent traditional electrofishing equipment from measuring natural behaviors in fish because a time delay can be allowed between disturbance (setting up the device) and the sample.

Nets have also been modified to sample fish in aquatic plant habitats. Tow nets for ichthyoplankton have been specially modified to sample larval fish in the shallow, congested habitats where traditional nets could not be easily used (Meador and Bulak 1987). The use of popnets and dropnets has been an effective sampling method for determining fish distribution, diversity, and abundance in dense vegetated and congested areas that traditional methods (i.e., seining and electrogear) are unable to sample (Wegener, Holcomb, and Williams 1973; Freeman, Greening, and Oliver 1984; Larson, Johnson, and Lynch 1986; Serafy, Harrell, and Stevenson 1988; Dewey, Holland-Bartels, and Zigler 1989; Morgan, Killgore, and Douglas 1988; Espegrin and Bergersen 1990). Since the popnets tested in pools and reservoirs proved to be accurate in sampling small fish associated with complex habitats (Larson, Johnson, and Lynch 1986), it is probably one of the better methods used to measure habitat use by juvenile fish. Light traps also appear to be a useful method for determining larval fish abundance in habitats that are difficult to sample by other means (Faber 1981, Gregory and Powles 1985).

Small areas of vegetation can be blocked off with nets, and rotenone applied (Lambout 1959). However, sample accuracy decreases with increase in plant density (Shireman, Colle, and DuRant 1981). This loss of accuracy is due to the difficulty in fish retrieval (Shireman, Colle, and DuRant 1981); similar problems have plagued electrosampling procedures in heavy vegetation (Layher and Maughan 1984, Killgore, Morgan, and Rybicki 1989). Zippen depletion estimation has been used to improve this type of sampling (Dewey 1991).

In addition, explosives have been used in sampling the abundance of fish populations (Averett and Stubbs 1962, Ferguson 1962, Bass and Hitt 1980, Metzger and Shafland 1986), but may not work efficiently in areas of soft, muddy substrate typically found under aquatic plants (Layher and Maughan 1984, Bayley and Austen 1988).

Management Goals

Plant control

Much attention has been focussed on controlling aquatic plants and the effects of control programs on freshwater systems (Table 4). Aquatic plants maintain diversity and ecosystem stability in aquatic systems (Odum 1969, Boyd 1971, Engel 1985, Gregg and Rose 1985), and the maintenance of specific plant density and plant configuration should be a major goal in management. Maintaining intermediate densities appears to be an important aspect of aquatic plant beds affecting the abundance, diversity, and growth of fish (Ware and Gasaway 1977; Savino and Stein 1982; Durocher, Provine, and Kraai 1984; Wiley et al. 1984; Engel 1985, 1988, 1990; Killgore, Morgan, and Rybicki 1989). It is especially important for the survival and recruitment of juvenile fishes (Aggus and Elliot 1975, Hall and Werner 1977, Gregory and Powles 1985, Gotceitas and Colgan 1987, Gutreuter and Anderson 1985, Mittelbach 1988, Meals and Miranda 1991, Cushing and Jia 1992).

Colle and Shireman (1980) predicted that the condition of largemouth bass would significantly decrease in systems with 40 percent or greater coverage of aquatic plants. The creation and maintenance of edges also may increase the availability of important forage and refuge habitat (Werner et al. 1977, Werner, Hall, and Werner 1978; Engel 1984). Based on these predicted benefits, moderate plant densities and plant edges, if maintained, should increase the growth and condition of harvestable fish and supply enough food and cover for the strong recruitment and survival of younger fish.

Fisherman's perspective and cost

There appear to be a number of sportfishing benefits (Surber 1961) to controlling aquatic plants. The fisherman's perspective and cost (Bryant 1970, Stott et al. 1971, Shireman, Colle, and Canfield 1986) are important factors to consider when prioritizing management goals (Surber 1961, Berry et al. 1975, Wiley et al. 1984). In a fisherman survey, only 55 to 62 percent thought aquatic plants posed a problem, and 84 percent of these people suggested that only a partial amount of the plants be removed; only 11 percent felt more emphasis should be placed on plant control (King, Raymong, and Buntz 1978). However, economic losses of fishing revenue have been recorded and are predicted with substantial increases of submersed vegetation in lakes and reserviors (Berry et al. 1975; Strange, Berry, and Schreck 1975; Colle et al. 1985, 1986, 1987; Borawa et al. 1978). Fishing effort has been shown to increase as much as 241 percent after much of the shoreline vegetation was removed (Mitzner 1978).

Summary

Many of the topics covered in this review represent recent theoretical works that directly apply to relationships between fish and their plant habitats. In addition, there has been extensive work in the area of plant management and indirect impacts on fish populations. However, the literature offers little empirical data to bridge the difference between theoretical predictions and management application.

More emphasis needs to be placed on the early life stages of fish when the relationship between plants and fish may be most important. More work is needed to better understand predator-prey relationships, and how both predatory and prey fishes use complex aquatic plant habitat. To understand these trophic interactions in reference to plant habitats, more attention should be directed towards well-designed behavioral studies, new ways of sampling, and experimental manipulations (McAllister and Peterman 1992) required to examine causes for distribution and habitat use. Additional effort should be directed to better define and quantify meaningful habitat parameters in aquatic plants. Finally, an interdisciplinary approach is required for a thorough understanding of fish/plant interactions. Cooperative studies must be conducted among fishery biologists, aquatic plant managers, aquatic ecologists, botanists, and limnologists.

3 Workshops on Fish/Plant Interactions

Background of Workshops

Two workshops were held to discuss data requirements, study designs, and research priorities concerning fish/plant interactions. The first workshop was held in New Orleans, Louisiana, in June 1992. Researchers from Federal, State, and academic institutions who are currently working with fish and aquatic plants were invited to present the results of their studies on fish/plant interactions and help develop work units in the new technology area (Table 5). The results of this workshop were used to define research topics and prepare for the second workshop.

The second workshop was held in Seattle, Washington, in July 1992 with the Field Review Group (FRG) and Program Managers Office of the Aquatic Plant Control Research Program (Table 6). The purpose of this workshop was to solicit input from the FRG on the importance of this topic to the overall program, to identify potential work units in the technology area, and to discuss the objectives and approach of each work unit.

Conclusions of the Workshops

Participants of both workshops fully supported the need for this research. Many ideas were expressed and various research areas were identified. The major conclusions are presented below.

a. Six work units in the new technology area were identified (Table 7). The objectives, approach, and interrelationships are discussed in Chapter 4 of this document.

b. Participants were briefed on current negotiations for a memorandum of agreement between WES and Bass Anglers Sportsman Society (BASS). BASS has expressed interest in WES's research on habitat

value of aquatic plants for fishes. This exemplifies the importance of the new technology area.

c. All participants fully supported a comprehensive literature review. They indicated that a document summarizing fish/plant research would help in developing research priorities and preparing environmental assessments of plant control operations. It was noted that the literature review should distinguish between a lack of data for a subject area and deficiencies in data for a subject area. Ultimately, the literature review will help justify funding requirements.

d. The effect of herbicides on fishes was noted as an important public relation concern that often creates controversy in operational treatment of problem aquatic plants. Coordination of research between the Chemical Control and Fish/Plant Technology areas in APCRP was suggested.

e. Selection of target fish species was briefly discussed. Community-level studies were preferred, but recreational fishes such as largemouth bass, bluegill, and crappie, should also be a major component of the research. The group emphasized that there should be a rationale for selecting target species and accounting for geographic variation in ichthyofaunal assemblages. An example was migratory fishes such as salmonids in the Columbia River.

f. Angler attitudes should be addressed in the technology area. Several ideas were expressed by the participants:

(1) Anglers are generally concerned how plant control operations affect the numbers of exploitable fishes either by direct mortality from treatment (mechanical harvester, herbicides) or habitat alteration.

(2) Aquatic plant managers need to know which plant habitats attract fishermen. Creel surveys would be one method of evaluating this question.

(3) Environmental concerns should be considered in aquatic plant management practices of the Corps of Engineers.

g. Sampling gear and sampling strategy were noted as an important consideration. Consistency in the sampling design between researchers was emphasized in order to ensure continuity and minimize bias.

h. There was consensus among the participants on objectives and approach presented for each work unit (see Chapter 4). Most discussion centered on the Habitat Classification and Management Strategy work units. Comments included:

(1) Structure of the plants (spatial configuration and density) should be emphasized more than species of plants in the habitat classification of aquatic plants. However, the establishment of exotic plants in a water body may have substantial effects on the composition of the native plant populations and should be considered in the initial classification scheme.

(2) The classification should incorporate regional differences in growing season, plant density, and possibly invertebrates and periphyton associated with the plant bed.

(3) The high variability in field data is problematic when evaluating cause and effect. The group agreed that well-defined studies with large sample sizes will be necessary to reduce the variability, but this problem will remain characteristic of aquatic plant research.

(4) The Management Strategies work unit needs to be better defined. Management strategies should be a series of demonstration projects that apply the results of the other work units to plant control operations. Benefits should be a separate component and used for cost justification of fishery habitat enhancement and plant control operations.

i. Considerable discussion ensued on the form of technology transfer, particularly by the FRG. In addition to technical reports containing quantitative multivariate relationships, a mechanistic model that relates the functional aspects of fish/plant interactions to plant control operations was suggested. For example, an aquatic plant manager can choose several spatial configurations of the plant bed and evaluate the response by largemouth bass according to feeding rates, reproductive success, and growth. Usable products should be in the form of fish/habitat relationships using response variables (e.g., growth and abundance of fish, harvest) that can be reasonably assessed. It is important to know which management strategies work, and why they work, so that successful management practices can be repeated.

4 Description of the Technology Area

Background of Technology Area

The purpose of this section is to describe an approach to develop quantitative relationships between aquatic plant habitats, fish abundance, and fish community structure for broad applicability within geographic regions and to discuss how fish/plant interactions can be used to develop fishery management strategies in vegetated water bodies. The literature review and the two workshops, which were the initial step in developing the technology area, served as a basis for prioritizing and designing studies on fish/plant interactions.

The technology area will have three primary requirements. First, results of each work unit must have a broad geographic application because the APCRP is a national research program. To meet this requirement, study sites will be selected in different regions of the United States where the Corps of Engineers is experiencing problems with fish/plant interactions. Secondly, a habitat-based approach is needed because aquatic plant managers directly modify habitat complexity through plant control programs. In addition, a habitat-based approach provides a common theme that researchers can use to compare study designs and results of individual projects. The final requirement is to have standardized collection methods to assess the composition and abundance of plants and fishes. This requirement is necessary to ensure that the results of work units are comparable when developing management strategies.

Organization of Work Units

The information gathered through the literature review and input obtained from the two workshops were used to identify six work units for the technology area:

a. Classification of Aquatic Plant Habitats for Fish.

b. Fish Distribution, Diversity, and Abundance in Vegetative Habitats.

c. Reproduction of Fish in Aquatic Plant Habitats.

d. Food Web Interactions.

e. Growth and Conditions of Fishes.

f. Strategies for Fisheries Management in Vegetated Water Bodies.

The interrelationships of the work units are graphically displayed with a flow chart (Figure 1). The flow chart divides the technology area into three components:

a. What are the types of fish habitats in plant beds? The habitat classification and the fish distribution, diversity, and abundance work units will address this question. The literature review and input from the workshops clearly showed that the quality of the habitat directly influences species composition and relative abundance of fishes. These two work units must be conducted concurrently because habitat type and fish association are intricately related. Therefore, the fist step in this research is to develop a classification scheme of aquatic plant habitats and describe the distribution, diversity, and abundance of fishes within each habitat. Both work units are more descriptive than causative evaluations, but the information derived from each is necessary to develop study designs for subsequent work units.

b. Why are the fish in those habitats? The next step is to evaluate why fishes use specific plant habitats. This question addresses functional use of habitats by fishes and will include the work units on reproduction, feeding, and growth. As the work units suggest, fish use plants for three primary reasons: reproducing, feeding while avoiding predators, and maintaining adequate growth rates and condition. The functional value of plants to fishes is an essential element in understanding the complex interactions of biotic and abiotic factors that regulate population maintenance and community structure. By studying functional processes in specific plant habitats, management strategies can be better developed because knowledge on spatial structure and relative abundance of plants will be part of the results. Both controlled and field studies will be used to verify and expand the understanding of functional value. Behavior interactions will be a key component of these studies. The results will allow researchers to show mechanistic responses of fish populations given different scenarios in plant habitat and fish species associations.

c. How should plant beds be managed as fish habitat? The final work unit will interrelate the results of the previous work units, evaluate limiting factors that influence fish/plant interactions, identify

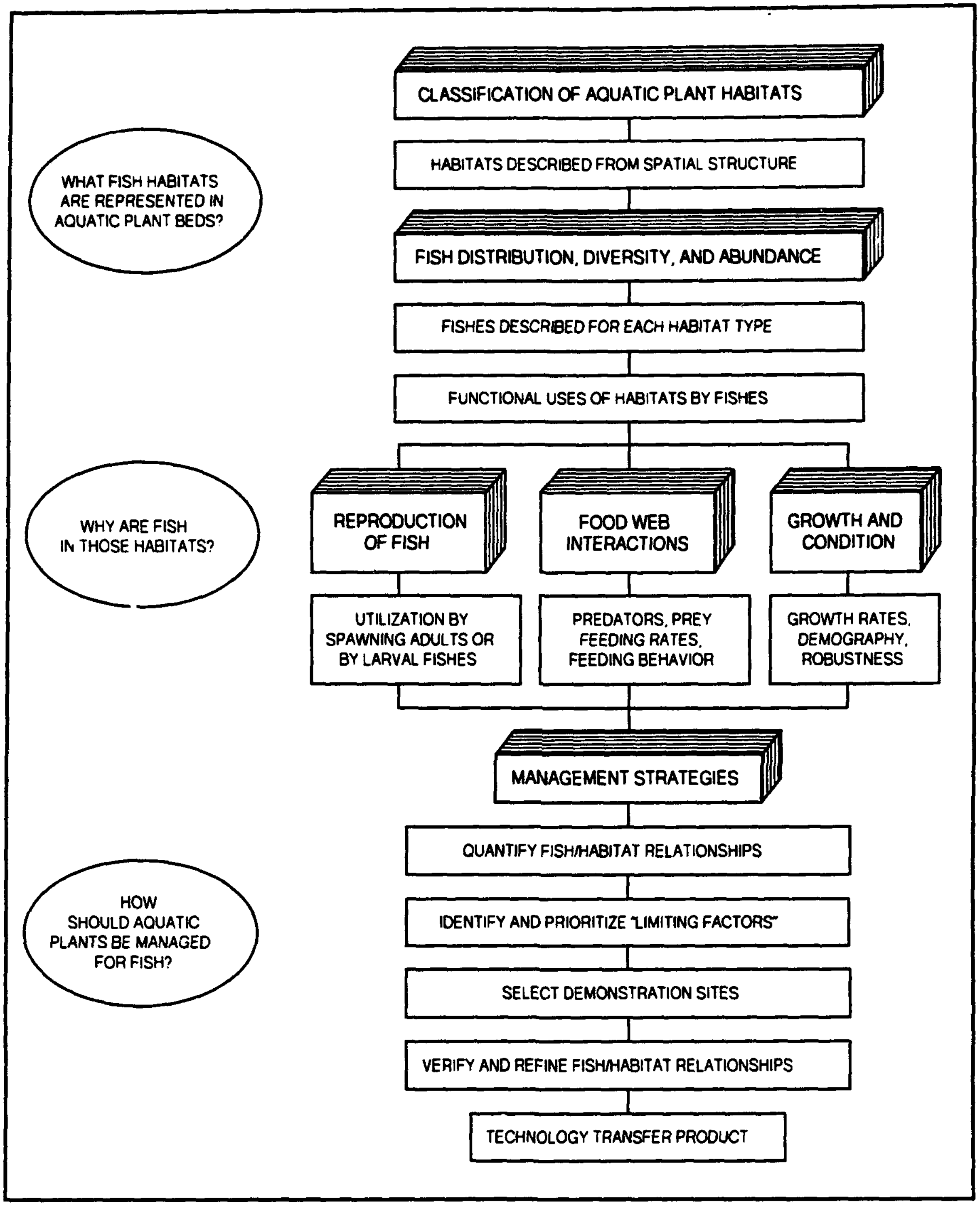


Figure 1. Organization of the technology area on fish/plant interactions. Circles represent research questions, boldface rectangles denote work units, and simple rectangles denote essential steps within each work unit.

causative factors for habitat use, and determine how aquatic plants should be managed for fish. Demonstration sites will be selected, and different management strategies will be applied. The results of the demonstration studies will ultimately be used to produce the technology transfer products that Corps of Engineers Districts can use to simulate and predict the outcome of different plant management strategies on fish.

Description of Work Units

Classification of aquatic plant habitats for fish

The purpose of this work unit is to develop a standardized system of classifying habitats created by aquatic plants. Aerial photography and biomass sampling are commonly used to evaluate aquatic plant beds. This work unit will consider these and other types of mapping techniques to determine their feasibility in distinguishing aquatic plant habitats. Relevant habitat variables that can be used to characterize plant beds and can be correlated with measures of the fish community (e.g. abundance and growth of sport fishes) will be identified. Emphasis will be placed on variables and techniques to describe the configuration and relative abundance of plant beds within a water body since these variables are directly influenced by plant control. Once individual habitats are defined, post-hoc analysis of the variables will be conducted to determine the adequacy of the habitat classification, and any modification of the classification matrix will be made as necessary.

Fish distribution, diversity, and abundance in vegetative habitats

Determining standardized system for collecting fish in vegetated habitats will be the initial objective of this work unit. As shown in the literature review, there are a variety of methods used to collect fish in plants including seining, electroshocking, rotenone, enclosure traps, light traps, and underwater observation techniques. Sampling gear recommendations will consider the biases and limitations of each gear type. Although study design is at the discretion of the researcher, fish-collecting techniques in subsequent work units will follow the guidelines developed in this work unit.

Once aquatic plant habitats have been defined in the first work unit, field studies will be conducted to quantify the composition and abundance of the fish community in each habitat. The primary objective will be to relate biological response variables (i.e., fish distribution, abundance, and diversity) to independent habitat variables created or regulated by aquatic plants (e.g., trophic status, water chemistry, plant biomass, and

distribution). Data will be collected at various locations across the United States to account for different types of water bodies, plant and fish assemblages, and geographic areas. Numerical relationships between fish and aquatic plants will be evaluated and developed using various analytical techniques including regression models, multivariate techniques (e.g., classification and ordination), and community indices (e.g., species diversity).

Reproduction of fish in aquatic plant habitats

Reproduction of fish in each aquatic plant habitat will be measured. Variables will include spawning periodicity, fecundity, nest density, survival rates, and richness and abundance of larvae. Both direct (underwater techniques) and indirect (e.g., light traps for larval fish) observations will be made in representative habitats. Correlations between nesting success and recruitment will be evaluated in water bodies where the population structure of fishes is regularly assessed by resource biologists. Ontogenetic shifts in habitat use will be determined by sampling over the entire reproductive season. The results of this work unit will describe the overall importance of aquatic plants to survival of embryos and larvae and provide a comprehensive list of species that use individual plant habitats for reproductive purposes.

Food web interactions

The purpose of this work unit is to determine relationships between aquatic plant habitats and foraging of individual species. The foraging environment of fishes is dependent on the complexity of the habitat, availability of food, and the influence of predators on foraging strategies. Foraging strategies are usually a behavioral response to the surrounding environment. The interaction of these factors makes it difficult to determine the importance of one plant habitat from another. Therefore, one approach will be to simulate distinct plant habitats in controlled environments (e.g., ponds) and measure the behavioral response of fishes relative to the presence of predators. These results may indicate that certain plant habitats optimize foraging success. Field experiments will also be conducted that correlate invertebrate assemblages with stomach contents of fishes in different plant habitats. If certain invertebrate food items are actively selected and if the habitat preferences of these food items are determined, then management can focus on specific plant configurations that optimize the habitat of commonly eaten invertebrates. The trophic state of the water body will be a primary consideration in establishing the composition and availability of food resources.

Growth and condition of fishes

Fishes of commercial or recreational value will be emphasized in this work unit. Two approaches will be used. First, growth of different age classes of fish will be compared between unvegetated and vegetated water bodies. These data will provide an objective evaluation on impacts of problem aquatic plant species that rapidly colonize unvegetated water bodies on fish growth. The second approach will be to compare growth rates of individual species among the predetermined plant habitats. Because of the difficulty in determining a fish's foraging history in large water bodies, pond studies will be emphasized. Response variables will include condition factors, relative weight indices, and absolute growth between years or seasons.

Strategies for fishes management in vegetated water bodies

This work unit will compile the results of the descriptive and functional studies into quantitative relationships between fish and aquatic plant habitats. Factors that limit the distribution and abundance of fishes will be identified and discussed. Demonstration projects will apply these relationships to reduce impacts of plant control on fish communities and to enhance fish habitat in areas with aquatic plants. Demonstrations will consist of modifying spatial configuration and density of plant beds at different field sites. In addition, experimental ponds at the Lewisville Aquatic Plant Research Facility will be used to demonstrate behavioral response of fishes to varying degrees of plant removal. The results of these demonstrations will be used to verify and refine fish/plant relationships and to compile a set of recommendations on distribution and abundance of plant beds for fishery management purposes.

Funding Sequence of the Work Units

The sequence of funding of each work unit is shown in Table 7. As noted previously, classification of aquatic plant habitats (Work Unit 1) and the fishes associated with each habitat (Work Unit 2) will be determined concurrently. The functional value of plant habitats will follow and include studies on reproduction, trophic dynamics, and growth and condition of fishes. The last work unit on management strategies will compile information from the previous work units, demonstrate fish/plant relationships emphasizing limiting factors, and produce workable models that plant managers can use to simulate and predict impacts of plant control operations.

References

Adams, M. S., and R. T. Prentki. 1992. Biology, metabolism and function of littoral submersed weedbeds of Lake Wingra, Wisconsin, USA. A summary and a review. Arch. Hydrobiol. Suppl. 62: 333-409.

Aggus, L. R., and G. V. Elliot. 1975. Effects of cover and food on year-class strength of largemouth bass. Pages 317-322 *in* R. H. Stroud, and H. Clepper, eds. Black bass biology and management. Sport Fishing Institute, Washington, DC.

Anderson, O. 1984. Optimal foraging by largemouth bass in structured environments. Ecology 65(3): 851-861.

Andrew, J. D., and A. D. Hasler. 1943. Fluctuations in the animal population of the littoral zone in Lake Mendota. Trans. Wis. Acad. Sci. Arts Lett. 35:175-185.

Armstrong, M. L., and A. V. Brown. 1985. Diel drift and feeding of channel catfish alevins in the Illinois River, Arkansas. Trans. Amer. Fish Soc. 112:302-307.

Avault, J. W., Jr. 1965a. Biological weed control with herbivorous fish. Proc. South. Weed. Conf. 18:590-591.

____________________ 1965b. Preliminary studies with grass carp for aquatic weed control. Prog. Fish Cult. 27:207-209.

Averett, R. C., and R. M. Stubbs. 1962. Toward a safe and effective method of using dynamite to sample fish populations and determine species ranges in large rivers. J. Tenn. Acad. Sci. 37:20-22.

Bailey, R. G. 1983. Delineation of ecosystem regions. Environ. Manage. 7:365-373.

Bailey, W. M. 1972. Arkansas' evaluation of the desirability of introducing the white amure (*Ctenopharyngodon idella* Val.) for control of aquatic weeds. Arkansas Game and Fish Comm. 59 pp.

______________________ 1975. Operational experiences with the white amure in weed control programs. Pages 75-78 *in* Proceedings of the symposium on water quality management through biological control, Report No. ENV-07-75-1, Univ. Fla., Gainesville.

______________________. 1978. A comparison of fish populations before and after extensive grass carp stocking. Trans. Am. Fish. Soc. 107:181-206.

Bain, M. B., J. T. Finn, and H. E. Booke. 1985a. A quantitative method for sampling riverine microhabitats by electrofishing. NAJMDP 5:489-493.

______________________. 1985b. Quantifying stream substrate for habitat analysis studies. NAJMDP 5:499-506.

Bain, M. B., and S. E. Boltz. 1992. Effect of aquatic plant control on the microdistribution and population characteristics of largemouth bass. Tran. Am. Fish. Soc. 121:94-103.

Baker, J. A., K. J. Killgore, and R. Kasul. 1991. Aquatic habitats and fish communities in the lower Mississippi River. Aquatic Sciences 3:313-356.

Balls, H., B. Moss, and K. Irvine. 1989. The loss of submerged plants with eutrophication.1: experimental-design, water chemistry, aquatic plant and phytoplankton biomass in experiments carried out in ponds in the Norfolk Broadland. Freshw. Biol. 22:71-87.

Barko, J. W., M. S. Adams, and N. L. Clesceri. 1986. Environmental factors and their consideration in the management of submersed aquatic plants. J. Aquatic Pl. Management 24:1-10.

Barko, J. W., R. M. Smart, M. S. Mathews, and D. G. Hardin. 1982. Sediment-submersed macrophyte relationships in freshwater systems, Tech. Report A-82-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Barko, J. W., R. M. Smart, M. S. Hennington, D. G. McFarland, and L. D. Fergunson. 1984. Effects of organic amendments to sediment on freshwater macrophyte growth. Tech. Rep. A-82-5, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Barnett, B. S. 1973. A technique for fish population sampling in dense submersed vegetation. Prog. Fish-Cult. 35:181-182.

Barnett, B. S., and R. W. Schneider. 1974. Fish populations in dense submersed plant communities. Hyacinth Control J 12:12-14.

Bass, Q. G., and V. G. Hitt. 1980. Qualitative sampling of warm-water fish with detonating cord. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 31:519-521.

Bayley, P. B., and D. J. Austen. 1988. Comparison of detonating cord and rotenone for sampling fish in warm water impoundments. NAJMDP 8:310-316.

Beach, M. L., W. W. Miley Jr., J. M. Van Dyke, and D. M. Riley. 1976. The effect of the Chinese grass carp (*Ctenopharynogodon idella* Val.) on the ecology of four Florida lakes and its use for aquatic weed control. Fla. Dep. Nat. Resour. 246 pp.

Beckett, D. C., T. P. Aartila, and A. C. Miller. 1992. Invertebrate abundance on potamogeton-nodosus effects of plant surface area and condition. Can. J. Zool. 70:300-306.

Berry, C. R., C. B. Schreck, R. Strange, S. Van Horn, and R. Corning. 1974. Aerial photographic monitoring of an aquatic macrophyte community following herbicide application. Va. J. Sci. 25:60.

Berry, C. R., C. B. Schreck, S. Van Horn, and R. Strange. 1975. Angler oriented objectives of an aquatic weed control program. Proc. Ann. Conf. Southeast Assoc. Game and Fish Comm. 29:301-309.

Bettoli, P. W. 1987. The restructuring of a forage fish community following large-scale aquatic vegetation control. Doctoral dissertation, Texas A&M University, College Station.

Bettoli, P. W., J. E. Morris, and R. L. Noble. 1991. Changes in the abundance of two atherinid species after aquatic vegetation removal. Trans. Am. Fish. Soc. 120:90-97.

Bettoli, P. W., M. J. Maceina, R. L. Noble, and R. K. Betsill. 1992. Response of a reservoir fish community to aquatic vegetation removal. NAJMDP (in press).

Bettoli, P. W., R. L. Noble, and R. K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. NAJMDP (in press).

Blackburn, R. D. 1975. Aquatic macrophytes and their problems. pages 5-7 *in* Proc. symposium on water quality management through biological control, Report No. ENV-07-75-1, Univ. Fla., Gainesville.

Boes, P., L. Van Ballegoijen, and J. Uunk. 1991. Changes in phosphorus cycling in a shallow lake due to food web manipulations. Freshw. Biol. 25(1):9-20.

Borawa, J. C., J. H. Kerby, M. T. Huish, and A. W. Mullis. 1978. Currituck Sound fish populations before and after infestation by Eurasian water-milfoil. Proc. Conf. S. E. Assoc. Game and Fish Comm. 32:520-528.

Bowes, T., A. S. Holaday, W. T. Haller. 1979. Seasonal variation in the biomass, tuber density, and photo-synthetic metabolism of hydrilla in three Florida lakes. J. Aquat. Plant Manage. 15:61-65.

Boyd, C.E. 1971. The limnological role of aquatic macrophytes and their relationship to reservoir management. Pages 153-166 *in* G.E. Hall, ed. Reservoir fisheries and limnology. Am. Fish. Soc. Spec. Publ. No. 8.

Bryant, C. B. 1970. Aquatic weed harvesting-effects and costs. Hyacinth Control J. 8:37-39.

Bryant, H. E., and A. Houser 1971. Population estimates and growth of largemouth bass in Beaver and Bull Shoals reservoirs. pages 349-357 *in* G. H. Hall ed. Reservoir fisheries and limnology. Am. Fish. Soc. Special Publ. No. 8.

Buck, H. D., R. J. Baur, and C. R. Rose. 1975. Comparison of the effects of grass carp and the herbicide Diuron in densely vegetated pools containing golden shiner and bluegills. Prog. Fish Cult. 37:185-190.

Canfield, D. E. Jr., J. V. Shireman, D. E. Colle, W. T. Haller, C. E. Watkins II, and M. J. Maceina. 1984. Prediction of chlorophyll-*a* concentrations in Florida lakes: Importance of aquatic macrophytes. Can. J. Fish. Aquat. Sci. 41:497-501.

Canfield, D. E. Jr., M. J. Maceina, and J. V. Shireman. 1983. Effects of hydrilla and grass carp on water quality in a Florida lake. Water Resours. Bull., Am. Water Resours. Assoc. 19(5):773-778.

Canfield, D. E. Jr., M. V. Hoyer, and C. M. Duarte. 1990. An empirical methods for characterizing standing crops of aquatic vegetation. J. Aquat. Plant Manage. 28:64-69.

Carpenter, S. R., and D. M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. Aquat. Bot. 26:341-370.

Carpenter, S. R., and N. J. McCreary. 1985. Effects of fish nests on pattern and zonation of submersed macrophytes in a softwater lake. Aquat. Bot. 22:21-32.

Cassani, J. R., and W. E. Caton. 1985. Effects of chemical and biologcial weed control on the ecology of a south Florida pond. J. Aquat. Plant Manage. 23:51-58.

Charnov, E. L., G. H. Orians, and K. Hyatt. 1976. Ecological implication of resource depression. Am. Nat. 100:247-259.

Chilton, E. W., and F. J. Margraf. 1990. Effects of fish predation on invertebrates associated with a macrophyte in Lake Onalaska, Wisconsin. J. Freshw. Ecol. 5:289-296.

Colgan, P., V. Gotceitas, and J. Frame. 1991. Individual variation, acquisition, and recquisition in a foraging task by juvenile bluegill sunfish (*Lepomis macrochirus*). J. Comp. Psycho. 105:78-84.

Colle, D. E. 1982. Hydrilla-miracle or migraine for Florida's sportfish. Aquatics 4(2):6.

Colle, D. E. and J. V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Trans. Am. Fisheries Soc. 109:521-531.

Colle, D.E., J. V. Shireman, D. E. Canfield, W. T. Haller, and J. C. Joyce. 1986. Economic loss results from hydrilla infestation. Aquaphyte 6:1-7.

Colle, D. E., J. V. Shireman, R. D. Gasaway, R. L. Stetler, and W. T. Haller. 1978. Utilization of selective removal of grass carp (*Ctenopharyngodon idella*) from an 80-hectare Florida Lake to obtain a population estimate. Trans. Am. Fisheries Soc. 107:724-729.

Colle, D. E., J. V. Shireman, and R. W. Rottmann. 1978. Food selection by grass carp fingerlings in a vegetated pond. Trans. Am. Fisheries Soc. 107:149-152.

Colle, D. E., J. V. Shireman, W. T. Haller, D. E. Canfield and J. C. Joyce. 1985. Influence of hydrilla on angler utiliztion, harvest, and monetary expenditure at Orange Lake, Florida. University of Fla., Gainesville, Florida. 22pp.

Colle, D, E., J. V. Shireman, W. T. Haller, J. C. Joyce, and D. E. Canfield Jr. 1987. Influence of hydrilla on harvestable sport-fish populations, angler use, and angler expenditures at Orange Lake, Florida. NAJMDP 7:410-417.

Colle, D. E., R. L. Cailteux, and J. V. Shireman. 1989. Distribution of Florida largemouth bass in a lake after elimination of all submersed aquatic vegetation. NAJMDP 9:213-218.

Connell, J. H. 1975. Some mechanisms producing structure in natural communities. Pages 460-491 *in* M. L. Cody and J. M. Diamond, eds. Ecology and evolution of communities. Belknap Press, Cambridge, Mass.

Cook, M. F., and E. P. Bergersen. 1988. Movements, habitat selection, and activity periods of northern pike in Eleven Mile Reservoir, Colorado. Trans. Am. Fisheries Soc. 117:495-502.

Cooper, W. E., and L. B. Crowder. 1979. Patterns of predation in simple and complex environments. pages 257-268 *in* R. H. Stroud and H. Clepper, eds. Predator-prey systems in fisheries management. Sport Fishing Institute, Washington, DC.

Cope, O., E. Wood, and G. Waller. 1970. Some chronic effects of 2,4-D in the bluegill (*Lepomis macrohirus*). Trans. Amer. Fisheries Soc. 99:1-12.

Crowder, L. B., and W. E. Cooper. 1979a. Effects of macrophyte removal on the feeding effciency and growth of sunfishes: evidence from pond studies. pages 251-268. *in* J. E. Creck, R. T. Prentki, and O. L. Louks, eds. Proc. aquatic plants lake management, and ecosystem consequences of lake harvesting. Institute from Environ. Studies, University of Wisconsin, Madison, WI.

____________________. 1979b. Structural complexity and fish-prey interactions in ponds: A point of view. Pages 2-10. *In* D. L. Johnson and R. A. Stein, eds. Response of fish to habitat structure in standing water. North Central Division Am. Fish. Soc. Spec. Publ. No. 6.

____________________. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802-1813.

Cushing, J. M.,and L. Jia. 1992. Intra-specific and density dependent juvenile growth. Bull. Math. Biol. 54(4):503-519.

Danehy, R. J., N. H. Ringler, and J. E. Gannon. 1991. Influence of nearshore structure on growth and diets of yellow perch (*Perca flavescens*) and white perch (*Morone amercana*) in Mexico Bay, Lake Ontario. J. Great Lakes Res. 17:183-193.

Dawson, F. H., E. Castellano, and M. Ladle. 1978. Concept of species succession in relation to river vegetation and management. Verh. Int. Ver. Theor. Angew. Limnol. 28:1129-1434.

Dewey, M. R. 1991. Quantitative sampling of juvenile fishes in vegetation. Res. Info. Bull., U. S. Dept. Int., Fish Wildl. Serv. No. 91-66

Dewey, M. R., L. E. Holland-Bartels, and S. J. Zigler. 1989. Comparison of fish catches with buoyant popnets and seines in vegetated and nonvegetated habitats. NAJMDP 9:249-253.

Devries, D. R., R. A. Stein, and P. L. Chesson. 1989. Sunfish foraging among patches: the patch-departure decision. Anim. Behav. 37:455-464.

DiCostanzo, A. J. 1957. Growth of bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*) of Clear Lake, Iowa. Iowa State J. Sci. 32:19-34.

Dibble, E. D. 1991. A comparison of diving and rotenone methods for determining relative abundance of fish. Trans. Am. Fisheries Soc. 120:663-666.

Diehl, S. 1988. Foraging efficiency of 3 freshwater fishes: effects of structural complexity and light. Oikos 53:207-214.

Downing, J. A., and M. A. Anderson. 1985. Estimating the standing biomass of aquatic macrophytes. Can. J. Fish. Aquat. Sci.42:1860-1869.

Duarte, C. M. 1987. Use of echo sounder tracings to estimate the above ground biomass of submerged plants in lakes. Can. J. Fish. Aquat. Sci. 44:732-735.

Dunst, R. C., S. M. Born, P. D. Uttormark, S. A. Smith, S. A. Knauer, S. L. Serns, D. R. Winter, and T. L. Wirth. 1974. Survey of lake rehabilitation techniques and experiences. Wis. Dept. Nat. Resour. Tech. Bull. 75. Madison, WI.

Durocher, P. P. , W. C. Provine, and J. E. Kraai. 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. NAJMDP 4:84-89.

Edwards, D. J., and E. Moore. 1975. Control of water seeds by grass carp in a drainage ditch in New Zealand. N. Z. J. Mar. Freshw. Res. 9:283-292.

Edwards, E. A. 1983. Habitat suitability index models: bigmouth buffalo. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.34. 23pp.

Edwards, E. A., and K. A. Twomey. 1982a. Habitat suitability index models: common carp. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.12. 27pp.

____________________. 1982b. Habitat suitability index models: smallmouth buffalo. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.13. 28pp.

Edwards, E. A., D. A. Krieger, G. Gebhart, and O. E. Maughan. 1982b. Habitat suitability index models: white crappie. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.7. 22pp.

Edwards, E. A., D. A. Krieger, M. Bacteller, and O. E. Maughan. 1982a. Habitat suitability index models: black crappie. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.6. 25pp.

Edwards, E. A., G. Gebhart and O. E. Maughan. 1983. Habitat suitability information: smallmouth bass. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.36. 47pp.

Ehlinger, T. J. 1989. Learning and individual variation in bluegill foraging: habitat-specific techniques. Anim. Behav. 38:643-658.

Ellis, D. V. 1961. Diving and photographic techniques for observing and recording salmon. J. Fisheries Res. Board Can. 18:1159-1166.

Engel, S. 1984. Restructuring littoral zones: a different approach to an old problem. Proceedings of the Third Annual Conference in 1983. Knoxville, TN, pp. 463-466.

____________________. 1985. Aquatic community interaction of submerged macrophytes. Wisconsin Dept. Nat. Resourc. Tech. Bull. No.156. pp 79.

____________________. 1988. The role and interactions of submersed macrophytes in a shallow Wisconsin lake. J. Freshw. Ecol. 4(3):329-342.

____________________. 1990a. Ecosystem responses to growth and control of submerged macrophytes: a literature review. Wis. Dept. Nat. Resour. Tech. Bull. 170. 1-16 pp.

____________________. 1990b. Ecological impacts of harvesting macrophytes in Halverson Lake, Wisconsin. J. Aquat. Plant Manage. 28:41-45.

Evans, D. O., B. A. Henderson, N. J. Bax, T. R. Marshall, R. T. Oglesby, and W. J. Christie. 1987. Concept and methods of community ecology applied to freshwater fisheries management. Can. J. Fish. Aquat. Sci. 44:448-470.

Espegrin, G. D., and E. P. Bergersen. 1990. Quantitative sampling of fish populations with a mobile rising net. NAJMDP 10:469-487.

Faber, D. J. 1981. A light trap to sample litteral and limnetic regions of lakes. Verh. Int. Ver. Theor. Angew. Limnol. 21:744-749.

Fausch, K., C. Hawkes, and M. Parsons. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-1985, Gen. Tech. Rep. PNW-BTR-213, U. S. For. Serv.

Ferguson, R. G. 1962. The effects of underwater explosives on yellow perch (*Perca flavescens*). Can. Fish. Cult. 29:31-39.

Flemer, D. A., and E. A. Woolcott. 1966. Food habits and distribution of the fishes of Tuckahoe Creek, Virginia, with special emphasis on the bluegill, *Lepomis m. macrochirus Rafinesque*. Chesapeake Sci. 7:75-89.

Floyd, K. B., R. D. Hoyt, and S. Timbrook. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Trans. Amer. Fisheries Soc. 113:217-223.

Forsberg, C. 1959. Quantitative sampling of subaquatic vegetation. Oikos 10:233-240.

Forester, T. S., and J. M. Lawrence. 1978. Effects of grass carp and carp on populations of bluegill and largemouth bass in ponds. Trans. Am. Fisheries Soc. 107:172-175.

Freeman, B. J., H. S. Greening, and J. D. Oliver. 1984. Comparison of three methods for sampling fishes and macroinvertebrates in a vegetated freshwater wetland. J. Freshw. Ecol. 2:603-606.

Gallagher, J. E. 1970. Aquatic weed control in the United States. Hyacinth Control J. 8:54-59.

Gangstad, E. O. 1971. Aquatic plant control program. Hyacinth Control J. 9:46-48.

Gerking, S. D. 1957. A method of sampling the littoral macrofauna and its application. Ecology 38:219-225.

__________________. 1962. Production and food utilization in a population of bluegill sunfish. Ecol. Monogr. 32:31-78.

Giles, J. H., and G. Zamora. 1973. Cover as a factor in habitat selection of juvenile brown (*Penaeus aztecus*) and white (*P. setiferus*) shrimp. Trans. Am. Fisheries Soc. 102:144-145.

Gilinsky, E. 1984. The role of fish predation and spatial heterogeneity in determining benthic community structure. Ecology 4:455-468.

Goldberg, D. E., and A. M. Barton. 1992. Patterns and consequences of interspecific competition in natural communities: a review of field experiments with plants. Am. Nat. 139(4):771-801.

Goldsborough, L. G., and G. G. C. Robinson. 1985. Seasonal succession of diatom epiphyton on dense mats of *Lemna minor*. Can. J. Bot. 63:2332-2339.

Goldstein, R. M. 1978. Quantitative comparison of seining and underwater observation for stream fishery surveys. Prog. Fish. Cult. 40:108-111.

Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507-515.

Gotceitas, V., and P. Colgan. 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. Trans. Am. Fisheries Soc. 116:40-49.

Goulder, R. 1969. Interactions between the rates of production of a freshwater macrophyte and phytoplankton in a pond. Oikos 20:300-309.

Gray, J., and D. W. Taylor. 1988. Evolution of freshwater ecosystem: the fossil record. Palaeogeoghr. Palaeoclimatol. Palaeoecol. 62:1-214.

Gregg, W. W., and F. L. Rose. 1985. Influences of aquatic macrophytes on invertebrate community structure, guild structure, and microdistribution in streams. Hydrobiologia 128:45-56.

Gregory, R. S., and P. M. Powles. 1985. Chronology, distribution, and sizes of larval fish sampled by light traps in macrophytic Chemung Lake. Can. J. Zool. 19:2569-2577.

Gutreuter, S. J., and R. O. Anderson 1985. Importance of body size to the recruitment process in largemouth bass populations. Trans. Am. Fisheries Soc. 114:317-327.

Haag, K. H., and G. R. Buckingham. 1991. Effects of herbicides and microbial insecticides on the insects of aquatic plants. J. Aquat. Plant Manage. 29:55-57.

Hall, D. J., W. E. Cooper, and E. E. Werner. 1970. An experimental approach to the production dynamics and structure of freshwater animal communities. Limn. Ocean. 15:839-928.

Hall, D. J. and E. E. Werner. 1977. Seasonal distribution and abundance of fishes in the littoral zone of a Michigan lake. Trans. Am. Fisheries Soc. 106:545-555.

Hall, D. J., E. E. Werner, J. F. Gilliam, G. G. Mittelbach, D. Howard, and C. G. Donfer. 1979. Diel foraging behavior and prey selection in the golden shiner (*Notemigonus crysoleucas*). J. Fisheries Res. Board of Can. 36:1029-1039.

Haller, W. T., and D. L. Sutton. 1975. Community structure and competition between hydrilla and vallisneria. Hyacinth Control J. 13:48-50.

Haller, W. T., J. V. Shireman, and D. F. DuRant. 1980. Fish harvest resulting from mechanical control of *Hydrilla*. Trans. Am. Fisheries Soc. 109:517-520.

Hamilton, K., and P. C. Nelson. 1984. Habitat suitability index models and instream flow suitability index curves: white bass. U. S. Fish Wildl. Serv. Biol. Rept. 82(10.89). 35 pp.

Hanson, J. M. 1990. Macroinvertebrate size-distribution of 2 contrasting freshwater macrophyte communities. Freshw. Biol. 24:481-491.

Hanson, J. M., and W. C. Leggett. 1986. Effect of competition between two freshwater fishes on prey consumption and abundance. Can. J. Fish. Aquat. Sci. 43:1363-1371.

Hargeby, A. 1990. Macrophyte associated invertebrates and the effect of habitat permanence. Oikos 57(3):338-346.

Harvey, R. M., G. G. Patterson, and J. R. Pickett. 1988. An automated positioning system for determining aquatic macrophyte distribution. J. Aquat. Plant Manage. 26:38-43.

Hawkes, C. L., D. L. Miller, and W. G. Layher. 1986. Fish ecoregions of Kansas stream fish assemblage patterns and associated environmental correlates. Environ. Biol. Fishes 17(4):267-280.

Heck, K. L., Jr., and T. A. Thoman 1981. Experiments on predator-prey interactions in vegetated aquatic habitats. J. Exper. Marine Biol. and Ecol. 53:125-134.

Heggenes, J., A. Brabrand, and S. J. Saltveit. 1990. Comparison of three methods for studies of stream habitat use by young brown trout and atlantic salmon. Tran. Am. Fisheries Soc. 119:101-111.

Heiskary, S. A., C. B. Wilson , and D. P. Larsen. 1987. Analysis of regional patterns in lake water quality: using ecoregions for lake management in Minnesota. Lake Reservoir Manage. 3:337-344.

Helfman, S. 1979. Fish attraction to floating objects in lakes. pages 49-57 *in* D. L. Johnson and R. A. Stein, eds. Response of fish to habitat structure in standing water. Am. Fish. Soc. Spec. Publ. No. 6.

__________________. 1981. The advantage to fishes of hovering in shade. Copeia 1981:392-400.

Hestand, R. S., B. E. May, D. P. Schultz, and C. R. Walker. 1973. Ecological implications of water levels on plant growth in a shallow water reservoir. Hyacinth Control 11:50-58.

Hestand, R. S., and C. C. Carter. 1978. Comparative effects of grass carp and selected herbicides on macrophyte and phytoplankton communities. J. Aquat. Plant Manage. 16:43-50.

Hinkle, J. 1985. The effects of a large scale fluridone treatment on the vegetation of Sampson Lake. Aquatics 7:8-10.

____________________. 1986. A preliminary literature review on vegetation and fisheries with emphasis on the largemouth bass, bluegill and hydrilla. Aquatics 8:9-14.

Hocutt, C. H., and E. O. Wiley. 1986. The zoogeography of North American freshwater fishes. Wiley and Sons, Inc. 866 pp.

Hoff, M. H. 1990. Effects of increased nesting cover on nesting and reproduction of smallmouth bass in northern Wisconsin lakes. Wis. Dept. Nat. Res. pp 22.

Holland, L. E., and M. L. Huston. 1984. Relationship of young-of-the-year northern pike to aquatic vegetation types in backwaters of the upper Mississippi river. NAJMDP 4:514-522.

Hoover, J. J., K. J. Killgore, and R. P. Morgan, Jr. 1988. Food habits of fishes associated with hydrilla beds and open water in Lake Seminole, Florida-Georgia. Proceedings, 23rd annual meeting, Aquatic Plant Control Research Program, Miscellaneous Paper A-89-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss, pp 202-218.

Howick, G. L., and W. J. O'Brien. 1983. Pisciborous feeding behavior of largemouth bass: an experimental analysis. Trans. Am. Fisheries Soc. 112:508-516.

Hubert, W. A., and R. T. Lackey. 1980. Habitat of adult smallmouth bass in a Tennessee river reservoir. Trans. Amer. Fisheries Soc. 109:364-370.

Huffaker, C B. 1958. Experimental studies on predator-prey oscillations. Hilgardia 27:343-383.

Hubbs, C. L., and R. M. Bailey. 1938. The small-mouthed bass. Cranbrook Inst. Sci., Bull. No. 10. 92 p.

Hulsey, A., Jr. 1959. A proposal for the management of reservoirs for fisheries. Proc. Annu. Conf. Southeast Assoc. Game Fish Comm. 12:132-143.

Hunter, M. D., and P. W. Price. 1992. Playing chutes and ladders-Heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. Ecology 73:724-732.

Inskip, P. D. 1982. Habitat suitability index models: northern pike. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.17. 40 pp.

Irvine, K., B. Moss, and H. Balls. 1989. The loss of submerged plants with eutrophication.2: relationships between fish and zooplankton in a set of experimental ponds, and conclusions. Freshw. Biol. 22:89-107.

Jackson, S. T., and D. F. Charles. 1988. Aquatic macrophytes in Adirondack (New York) lakes: patterns of species composition in relation to environment. Can. J. Bot. 66:1449-1460.

Janecek, J. A. 1988. Literature review on fishes interaction with aquatic macrophytes with special reference to the Upper Mississippi River System. Upper Mississippi River Conservation Committee Fish. Section, Rock Island, IL. 57 pp.

Jennings C. A., M. R. Dewey, and P. A. Vohs 1991. Classification of aquatic macrophytes with aerial videography. U.S. Dept. of Int., Fish and Wildl. Serv., Res. Inf. Bull. No. 91-69.

Johnson, R. E., and M. R. Bagwell. 1979. Effects of mechanical cutting on submerged vegetation in a Louisiana lake. J. Aquat. Plant Manage. 17:54-57.

Johnson, D. L., R. A. Beaumier, and W. E. Lynch Jr. 1988. Selection of habitat structure interstice size by bluegills and largemouth bass in ponds. Trans. Am. Fisheries Soc. 117:171-179.

Kautsky, H., B. Widbom, and F. Wulff. 1981. Vegetation, macrofauna and benthic meiofauna. Ophelia 20:53-77.

Keast, A. 1985a. Development of dietary specializations in a summer community of juvenile fishes. Environ. Biol. Fishes 13:211-224.

___________________. 1985b. Planktivory in a littoral-dwelling lake fish association: prey selection and seasonality. Can. J. Fish. Aquat. Sci. 42:1114-1126.

Keast, A., and J. Harker. 1977. Strip counts as means of determining densities and habitat utilization patterns in lake fishes. Environ. Biol. Fishes 1:181-188.

Keast, A., and D. Webb. 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake, Lake Opinicon, Ontario. J. Fisheries Res. Board Can. 23:1845-1974.

Kieffer, J. D., and P. W. Colgan. 1991. Individual variation in learning by foraging pumpkinseed sunfish, *Lepomis gibbosus*: the influence of habitat. Anim. Behav. 41:603-611.

___________________. 1992. The role of learning in fish behaviour. Rev. Fish Biol. Fish. 2:125-143.

Killgore, K. J., R. P. Morgan, and N. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. NAJMDP 9:101-111.

Kimmel, B. L., and A. W. Groeger. 1986. Limnological and ecological changes associated with reservoir aging. pages 103-109 *in* G. E. Hall and M. J. Van Den Avyle, eds. Reservoir fisheries management: strategies for the 80's. Reservoir Committee, Southern Division Trans. Am. Fisheries Soc., Bethesda, MD.

King, T. R., R. R. Raymond, and J. C. Buntz. 1978. Comparison of attitudes of average fishermen and fishing club members. Proc. Ann. Conf. Southeast Assoc. Game Fish Comm. 32:657-665.

Klussmann, W. K. 1988. Control of aquatic macrophytes by grass carp in Lake Conroe, Texas, and the effects on the reservoir ecosystem. Miscellaneous Publication 1664, Texas Agricultural Experiment Station, College Station, TX.

Koegel, R. G., D. F. Livermore, and H. D. Bruhn. 1977. Costs and productivity in harvesting of aquatic plants. J. Aquat. Plant Manage. 15:12-17.

Kramer, R. H., and L. L. Smith Jr. 1962. Formation of year classes in Largemouth bass. Trans. Am. Fisheries Soc. 91:29-41.

Krecker, F. H. 1939. A comparative study of the animal population of certain submerged aquatic plants. Ecology 20:553-562.

Krieger, D. A., J. W. Terrell, and P. C. Nelson. 1983. Habitat suitability index information: yellow perch. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-83/10.55. 37 pp.

Krzywosz, T., W. Krzywosz, and J. Radziej. 1980. The effects of grass carp, *Ctenopharyngodon idella* (Val.), on aquatic vegetation and ichthyofauna of Lake Dgal Wielki. Ekol. Pol. 28:433-450.

Lambout, V. W. 1959. Block-off net for taking fish population samples. Prog. Fish. Cult. 21:143-144.

Langeland, K. A., S. B. Linda, and W. T. Haller. 1985. Relationships between water transparency and maximum depths of macrophytes colonization in lakes. J. Aquat. Plant Manage. 23:25-28.

Lantz, K. E., J. T. Davis, J. S. Hughes, and H. E. Schafer Jr. 1964. Water level fluctuations: effects on vegetation control and fish population management. Proc. Ann. Conf. Southeast Assoc. Game Fish Comm. 18:1-12.

Larson E. W., D. L. Johnson, and W. E. Lynch. 1986. A buoyant popnet for accurately sampling artificial habitat structures. Tran. Amer. Fisheries Soc. 115:351-355.

Latta, W. C. 1963. The life history of the smallmouth bass. *Micropterus d. dolomieui* at Waugoshance Point, Lake Michigan. Mich. Dep. Conserv. Inst. Fish. Res. Bull. No. 5. 56p.

Laughlin, D. R., and E. E. Werner. 1980. Resource partitioning in coexisting sunfish: pumpkinseed (*Lepomis gibbosus*) and northern longear sunfish (*Lepomis megalotis*). Can. J. Fish. Aquat. Sci. 27:1411-1420.

Layher, W.G., and O.E. Maughan. 1984. Comparison in efficiencies of three sampling techniques for estimating fish populations in small stream. Prog. Fish Cult. 46:180-184.

Layzer, J. B., and M. D. Clady. 1987. Phenotypic variation of young-of-year bluegills *Lepomis-macrochirus* among microhabitats. Copia 3:702-707.

____________________. 1991. Microhabitat and diet segregation among coexisting young-of-year sunfishes. Nat. Ocean. Atmosph. Admin. Nat. Mar. Fish. Serv. Tech. Rep. 95. 99-108 pp.

Lembi, C. A., B. G. Ritenour, E. M. Iverson, and E. C. Forss. 1978. The effects of vegetation removal by grass carp on water chemistry and phytoplankton in Indiana ponds. Trans. Am. Fisheries Soc. 107:161-171.

Lodge, D. M. 1985. Macrophyte-gastropod associations: observations and experiments on macrophyte choice by gastropods. Freshw. Biol. 15:695-708.

Lukens, J. E. 1967. Mapping of submerged aquatic vegetation in Cayuga Lake using color aerial photography. Div. Water Resourc., New York State Conserv. Dept. 1-12 pp.

Lynch, W. E. Jr., and D. L. Johnson. 1989. Influences of interstice size, shade, and predators on the use of artificial structures by bluegills. NAJMDP 9:219-255.

Lyons, J. 1989. Correspndence between the distribution of fish assemblages in Wisconsin USA streams and Omernik's ecoregions. Am. Midl. Nat. 122(1):163-182.

Machena, C., and N. Kautsky. 1988. A quantitative diving survey of benthic vegetation and fauna in Lake Kariba, a tropical man-made lake. Freshw. Biol. 19:1-14.

Maceina, M. J., and J. V. Shireman. 1980. The use of a recording fathometer for determination of distribution and biomass of hydrilla. J. Aquat. Plant Manage. 18:34-39.

Maceina, M. J., and J. V. Shireman. 1985. Influence of dense hydrilla infestation on black crappie growth. Proc. Annu. Conf. Southeast Assoc. Game Fish Comm. 36:394-402.

Maceina, M. J., J. V. Shireman, K. A. Langeland, and D. E. Canfield Jr. 1984. Prediction of submersed plant biomass by use of a recording fathometer. J. Aquat. Plant Manage. 22:35-38.

Maceina, M. J., P. W. Bettoli, W. G. Klussmann, R. K. Betsill, and R. L. Noble. 1991. Effect of aquatic macrophyte removal on recruitment and growth of black crappies and white crappies in Lake Conroe, Texas. NAJMDP 11:556-563.

Macon, T. T. 1966. Predation by *Salmo trutta* in a moorland fishpond. Int. Ver. Theor. Angew. Limnol. Verh. 16:1081-1087.

Martin-Bergmann, K. A., and J. H. Gee. 1985. The central mudminnow *Umbra-limi*; a habitat specialist and resource generalist. Can. J. Zool. 63(8):1753-1764.

Martin, R. D., R. L. Noble, P. W. Bettoli, and R. C. Maggio. 1986. Mapping aquatic weeds with aerial color photography and evaluating their control by grass carp *Ctenopharyngodon-idella*. J. Aquat. Plant Manage. 24:46-56.

McAllister, M. K., and R. M. Peterman. 1992. Experimental design in the management of fisheries: a review. NAJMDP 12:1-18.

McGehee, J. T. 1979. Mechanical hydrilla control in Orange Lake, Florida. J. Aquat. Plant Manage. 17:58-60.

McMahon, T. E. 1982. Habitat suitability index models: creek chub. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.4. 500 pp.

McMahon, T. E., and J. W. Terrell. 1982. Habitat suitability index models: channel catfish. U.S. Dept. Int., Fish . Wildl. Serv. FWS/OBS-82/10.2. 21 pp.

McMahon, T. E., J. W. Terrel, and P. C. Nelson. 1984. Habitat suitability information. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.56. 43 pp.

McMahon, T. E., G. Gehart, O. E. Maughan, and P. C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: warmouth. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.67. 21 pp.

Meador, M. R., and J. S. Bulak. 1987. Quantifiable ichthyoplankton sampling in congested shallow water areas. J. Freshw. Ecol. 4:65-69.

Meals, K. O., and L. E. Miranda. 1991. Variability in abundance of age-0 centrarchids among littoral habitats of flood control reservoirs in Miss. NAJMDP 11:298-304.

Mesing, C. L., and A. M. Wicker. 1986. Home range, spawning migrations, and homing of radio-tagged Florida largemouth bass in two central Florida lakes. Trans. Am. Fisheries Soc. 115:286-295.

Metzger, R. J., and P. L. Shafland. 1986. Use of detonating cord for sampling fish. NAJMDP 6:113-118.

Mikol, G. F. 1985. Effects of harvesting on aquatic vegetation and juvenile fish populations at Saratoga Lake, New York. J. Aquat. Plant Manage. 23:59-63.

Miley, W. W., Jr., A. J. Leslie, Jr., and J. M. Van Dyke. 1979. The effects of the grass carp (*Ctenopharyngodon idella* Val.) on vegetation and water quality in three central Florida lakes. Final Rep. Fla. Dept. Nat. Res.

Milinski, M., and R. Heller. 1978. Influence of a predator on the optimal foraging behavior of sticklebacks (*Gasterosteus aculeatus* L.). Nature 275:642-644.

Miller, A. C., D. C. Beckett, C. M. Way, and E. J. Bacon. 1989. The habitat value of aquatic macrophytes for macroinvertebrates. Technical Report A-89-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Miller, D., and R. H. Kramer. 1971. Spawning and early life history of largemouth bass (*Micropterus salmoides*) in Lake Powell. Am. Fish. Soc. Special Pub. 8:78-83.

Miranda, L. E., W. L. Shelton, and T. D. Bryce. 1984. Effects of water level manipulation on abundance, mortality and growth of young-of-year largemouth bass in West Point Reservoir, Alabama-Georgia. NAJMDP 4:314-320.

Mittelbach, G. G. 1981. Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. Ecology 62:1370-1386.

__________________. 1984. Predation and resource partitioning in two sunfishes (Centrarchidae). Ecology 65:499-513.

__________________. 1988. Competition among refuging sunfishes and effects of fish density on littoral zone invertebrates. Ecology 69:614-623.

Mittelbach, G. G., and P. L. Chesson. 1987. Predation risk: indirect effects on fish populations. Pages 315-330 *in* C. W. Kerfoot, and A. Sih, ed. Predation: direct and indirect impacts on aquatic communities. University Press of New England, Hanover, and London.

Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. Trans. Am. Fisheries Soc. 107:135-145.

Modde, T., R. C. Ford, and M. G. Parsons. 1991. Use of a habitat-based stream classification system for categorizing trout biomass. NAJMDP 11:305-311.

Morgan, R. P., K. J. Killgore, and N. H. Douglas. 1988. Modified popnet design for collecting fishes in varying depths of submersed aquatic vegetation. J. Freshw. Ecology 4:533-539.

Morin, J. O., and K. D. Kimball. 1984. Relationship of macrophyte-mediated changes in the water column to periphyton composition and abundance. Freshw. Biol. 14:367-370.

Mraz, D. 1964. Observations on large and smallmouth bass nesting and early life history. Wis. Conserv. Dept. Res. Rep. No. 11 (Fisheries). 13 pp.

Moxley, D. J., and F. H. Langford. 1982. Beneficial effects of *Hydrilla* on two eutrophic lakes in central Florida. Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm. 36:280-286.

Murdoch, W. W., and A. Oaten. 1975. Predation and population stability. Adv. Ecol. Res. 9:1-131.

Murphy, K. J., and J. W. Eaton. 1981. Waterplants, boat traffic and angling in canals. British Freshwater Fisheries 2nd Conference Proceedings. pp 173-187.

Nichols, S. F., D. W. Schloesser, and J. W. Geis. 1988. Seasonal growth of the exotic submersed macrophyte *Nitellopsis obtusa* in the Detroit River of the Great Lakes, USA, Canada. Can. J. Bot. 66(1):116-118.

Noble, R. L. 1981. Management of forage fishes in impoundments of the southern United States. Trans. Am. Fisheries Soc. 110:738-750.

____________________. 1986. Predator-prey interactions in reservoir communities. pages 137-143 *in* G. E. Hall, and M. J. Van Den Avyle, eds. Reservoir fisheries management: strategies for the 80's. Am. Fish. Soc., Southern Div. Res. Comm., Bethesda, MD.

Northcote, T. G., and D. W. Wilkie. 1963. Underwater census of stream fish populations. Trans. Am. Fisheries Soc. 92:146-151.

Odum, E. P. 1969. The strategy of ecosystem development. Science 164:262-270.

Olla, B. L., and M. W. Davis. 1989. The role of learning and stress in predator avoidance of hatchery-reared coho salmon (*Oncorhynchus kisutch*) juveniles. Aquaculture 76:209-214.

Opuszynski, K. 1972. Use of phytophagous fish to control aquatic plants. Aquaculture 1:61-79.

Osborne, J. A., D. I. Richard, and J. W. Small, Jr. 1983. Environmental effect and vegetation control by grass carp (*Ctenopharyngodon idella* Val.) and herbicides in four Florida Lakes. Final Report, Florida Dept. Nat. Resour. Tallahassee, Florida, 431 pp.

Osborne, J. A. 1985. A preliminary study of the efficacy of hybrid grass carp *Ctenopharyngodon-idella x Aristichthys-nbilis* for *Hydrilla-verticillata* control. J. Aquat. Plant Manage. 23:16-20.

Osenberg, C. W., E. E. Werner, G. G. Mittelbach, and D. J. Hall. 1987. Growth patterns in bluegill (*Lepomis macrochirus*) and pumpkinseed (*L.gibbosus*) sunfish: environmental variation and the importance of ontogenetic niche shifts. Can. J. Fish. Aquat. Sci. 45:17-26.

Paller, M. H. 1987. Distribution of larval fish between macrophyte beds and open channels in a southeastern floodplain swamp. J. Freshw. Ecology 4:191-200.

Pardue, G. P. 1973. Production response of the bluegill sunfish, *Lepomis macrochirus* to added attachment surface for fish-food organisms. Tran. Am. Fisheries Soc. 102:622-626.

Pardue, G. B., and L. A. Nielsen. 1979. Invertebrate biomass and fish production in ponds with added attachment surface. Pages 34-43 *in* D. L. Johnson, and R. A. Stein, eds. Response of fish to habitat structure in standing water. Am. Fish. Soc. Spec. Publ. 6.

Petrell, R. J., L. O. Bagnall, and G. H. Smerage. 1991. Physical description of water hyacinth mats to improve harvester design. J. Aquat. Plant Manage. 29:45-50.

Pflieger, W. L., M. A. Schene, and P. S. Haverland. 1981. Techniques for the classification of stream habitats, with examples of their application in defining the stream habitats of Missouri; pages 362-368 *in* N. B. Armantrout, ed. Acquisition and utilization of aquatic habitat inventory information: proceedings of a symposium. Am. Fish. Soc., Bethesda, MD.

Phillips, G. L., D. Eminson, and B. Moss. 1978. A Mechanism to Account for Macrophyte Decline in Progressively Eutrophicated Freshwaters. Aquat. Bot. 4:103-126.

Pine, R. T., L. W. J Anderson, and S. S. O. Hung. 1989. Non-destructive estimation of aquatic macrophyte biomass. J. Aquat. Plant Manage. 27:47-49.

____________________. 1990. Control of aquatic plants in static and flowing water by yearling triploid grass carp. J. Aquat. Plant Manage. 28:36-40.

Poe, T. P., C. O. Hatcher, C. L. Brown, and D. W. Schloesser. 1986. Comparison of species composition and richness of fish assemblages in altered and unaltered littoral habitats. J. Freshw. Ecol. 3:525-536.

Polunin, N. V. C. 1984. The decomposition of emergent macrophytes in fresh water. Adv. Ecol. Res. 14:115-166.

Power, M. E. 1992. Top-down and bottom-up forces in food webs: do plants have premacy. Ecology 73:733-746.

Power, M. E., W. J. Mathews, and A. J. Stewart. 1985. Grazing minnows, piscivorous bass, and stream algae: dynamics of a strong interaction. Ecology 66:1448-1456.

Pringle, J. D. 1984. Efficiency of various quadrate sizes used in benthic sampling. Can. J. Fish. Aquat. Sci. 41:1485-1489.

Pringle, C. M., R. J. Naiman, G. Bretschko, J. R. Karr, M. W. Oswood, J. R. Webster, R. L. Welcomme, and M. J. Winterbourn. 1988. Patch dynamics in lotic systems: the stream as a mosaic. J. N. Am. Benthol. Soc. 7:503-524.

Probst, W. E., C. F. Rabeni, W. G. Covington, and R. E. Marteney. 1984. Resource use by stream-dwelling roc bass and smallmouth bass. Trans. Amer. Fisheries Soc. 113:283-294.

Prowse, G. A. 1971. Experimental criteria for studying grass carp feeding in relation to weed control. Prog. Fish Cult. 33:128-131.

Quade, H. W. 1969. Cladoceran faunas associated with aquatic macrophytes in some lakes in northwestern Minnesota. Ecology 50:170-179.

Quinn, T. P., and A. H. Dittman. 1990. Pacific salmon migrations and homing: mechanisms and adaptive significance. Trends Ecol. Evol. 5:174-177.

Raleigh, R. H. 1982. Habitat suitability index models: brook trout. U. S. Dept. Int., Fish. Wildl. Serv. FWS/OBS-82/10.24. 42 pp.

Raleigh, R. H., T. Hickman, R. C. Solomon, and P. C. Nelson. 1984. Habitat suitability information: rainbow trout. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.60. 64 pp.

Raleigh, R. H., L. D. Zuckerman, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability index curves: brown trout, revised. U.S. Fish and Wildl. Serv. Biol. Report 82(10.124). 65 pp.

Reinert, K. H., M. L. Hinman, and J. H. Rodgers Jr. 1988. Fate of endothall during the Pat Mayse Lake, Texas aquatic plant management program. Arch. Environ. Contam. Toxicol. 17(2):195-200.

Reynolds, A. J., and J. W. Eaton. 1983. The role of vegetation structure in a canal fishery. Proc. Third British Freshwater Fisheries Conf., 192-202.

Rodgers, J. D., M. F. Solazzi, S. L. Johnson, and M. A. Buckman. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. NAJMDP 12:79-86.

Rohm, C. M., J. W. Giese, and C. C. Bennett. 1987. Evaluation of an aquatic ecoregion classification of streams in Arkansas. J. Freshw. Ecol. 4(1):127-140.

Rosenzweig, M. L. 1991. Habitat selection and population interactions: the search for mechanism. Am. Nat. 137:5-28.

Rosine, W. N. 1955. The distribution of invertebrates on submerged aquatic plant surfaces in Juskee Lake, Colorado. Ecology 36:308-314.

Rottman, R. W., and R. O. Anderson 1978. Limnological and ecological effects of grass carp in ponds. Proc 30th Annu. Conf. Southeast Assoc. Game Fish Comm.

Rowe, D. K. 1984. Some effects of eutrophication and the removal of aquatic plants by grass carp *Ctenopharyngodon-idella* on rainbow trout *Salmo-gairdneri* in Lake Parkenson, New Zealand. N. Z. J. Mar. Freshw. Res. 18(2):115-128.

Rozas, L. P., and W. E. Odum. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. Oecologia 77:101-106.

Rybicki, N. B., R. T. Anderson, J. M. Shapiro, K. L. Johnson, and C. L. Schuleman. 1987. Data on the distribution and abundance of submersed aquatic vegetation in the tidal Potomac River and estuary,

Maryland, Virginia, and the District of Columbia, 1986. U. S. Geol. Surv. Rep. (open file) 87-575. Reston, VA.

Saiki, M. K., and J. C. Tash. 1979. Use of cover and dispersal by crayfish to reduce predation from largemouth bass. pages 44-48 *in* D. L. Johnson and R. A. Stein, eds. Response of fish to habitat structure in standing water. North Central Division Am. Fish. Soc. Spec. Publ. 6.

Savino, J. F., and R. A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Trans. Am. Fisheries Soc. 11:255-266.

Savino, J. F., R. A. Stein, and E. A. Marschall. 1985. Management of macrophyte communities to enhance largemouth bass and bluegill populations at Clark Lake.

______________________. 1992. Bluegill growth as modified by plant-density: an exploration of underlying mechanisms. Oecologia 89:153-160.

Scheffer, M., A. A. Achterberg, and B. Beltman. 1984. Distribution of macroinvertebrates in a ditch in relation to the vegetation. Freshw. Biol. 14:367-370.

Scheffer, M., M. R. Deredelijkheid, and F. Noppert. 1992. Distribution and dynamics of submerged vegetation in a chain of shallow eutrophic lakes. Aquat. Bot. 42:199-216.

Schmitt, R. J., and S. J. Holbrook. 1985. Patch selection by juvenile black surf perch (Embiotochidae) under variable risk: interactive influence of food quality and structural complexity. J. Exp. Mar. Biol. Ecol. 85:269-285.

Schloesser, D. W., and B. A. Manny. 1984. Rapid qualitative method for estimating the biomass of submersed macrophytes in large water bodies. J. Aquat. Plant Manage. 22:102-104.

Schramm, H. L. Jr., L. J. Jirka, and M. V. Hoyer. 1987. Epiphytic macroinvertebrates on dominant macrophytes in two central Florida Lakes. J. Freshw. Ecol. 4:151-162.

Scott, S. L., and J. A. Osborne. 1981. Benthic macroinvertebrates of a hydrilla-infested Central Florida Lake. J. Freshw. Ecol. 1:41-49.

Serafy, J.E., R.M. Harrell, and J.C. Stevenson. 1988. Quantitative sampling of small fish in dense vegetation: design and field testing of portable "popnets." J. Appl. Ichthyol. 4:149-157.

Shireman, J. V., and M. J. Maceina. 1979. Techniques utilizing a recording fathometer in determining distribution and biomass of *Hydrilla verticilata* Royle. Inst. Food. Agricult. Sci., Aquat. Weeds Res. Center, Final Report. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shireman, J. V., and M. J. Maceina. 1981. Utilization of grass carp, *Ctenopharyngodon idella* Val. for hydrilla control in Lake Baldwin, Florida. J. Fish Biol. 19:629-636.

Shireman, J. V., and W. T. Haller. 1980. The ecological impact of integrated chemical and biological aquatic weed control. Annu. Rep. Environ. Prot. Agency, FL, 804597-02, 346 pp.

Shireman, J. V., D. E. Canfield, D. E. Colle, D. F. DuRant, and W. T. Haller. 1984. Evaluation of biological, chemical, and mechanical aquatic vegetation control upon fish populations in 0.2 Ha. research ponds. Center for Aquatic Weeds, Gainesville, FL 32606.

Shireman, J. V., D. E. Colle, and D. F. DuRant. 1981. Efficiency of rotenone sampling with large and small block nets in vegetated and open-water habitats. Trans. Amer. Fisheries Soc. 110:77-80.

Shireman, J. V., D. E. Colle, D. E. Canfield Jr. 1986. Efficiency and cost of aquatic weed control in small ponds. Water Res. Bull. 22(1):6.

Shireman, J. V., M. V. Hoyer, M. J. Maceina, and D. E. Canfield, Jr. 1985. The water quality and fishery of Lake Baldwin, Florida, 4 years after macrophyte removal by grass carp. pages 201-206 *in* Lake and reservoir management: practical application, N. Am. Lake Manage. Soc.

Sih, A. 1987. Predators and prey lifestyles: an evolutionary and ecological overview. *in* W. C. Kerfoot and A. Sih eds. Predation: direct and indirect impacts on aquatic commuinities. University Press, Hanover, NH.

Sills, J. B. 1964. A report on the use of Karmex to control filamentous algae in fish ponds. Proc. Annu. Conf. Southeastern Assoc. Game Fish Comm. 18:474-479.

Singh, S. B., K. K. Sukumaran, K. K. Pillai, and P. C. Chakrabarti. 1969. Observations on efficacy of grass carp (*Ctenopharyngodon idella* Val.) in controlling and utilizing aquatic weeds in ponds in India. Indo-Pac. Fish. Coun. Proc. 12(11):220-235.

Sliger, W. A., J. W. Henson, and R. C. Shadden. 1990. A quantitative sampler for biomass estimates of aquatic macrophytes. J. Aquat. Plant Manage. 28:100-102.

Slaney, P. A., and A. D. Martin. 1987. Accuracy of underwater census of a trout population in a large stream in British Columbia. NAJMDP 7:117-122.

Smart, R. M., and J. W. Barko. 1988. Effects of water chemistry on aquatic plants: interrelationships among biomass production, plant nutrition, and water chemistry. Final Report No. A-88-5, U.S. Army Corps of Engineers. 26 pp.

Smith, F. E. 1961. Bottom fauna in a fertilized natural lake and its utilization by trout (*Salvelinus fontinalis*). Int. Ver. Theor. Angew. Limnol. Verh. 14:722-726.

Smith, F. E. 1972. Spatial heterogeneity, stability and diversity in ecosystems. Trans. Conn. Acad. Arts Sci. 44:309-335.

Smith, S. L., and J. E. Crumption. 1977. Interrelatinships of vegetative cover and sun fish population density in suppressing spawning in largemouth bass. Proc. Ann. Conf. Southeastern Assoc. Game and Fish Comm. 31(1977):141-157.

Spencer, C. N., and D. L. King. 1984. Role of fish in regulation of plant and animal communities in eutrophic ponds. Can. J. Fish. Aquat. Sci. 41:1851-1855.

Stein, R. A., and J. J. Magnuson. 1976. Behavorial response of crayfish to a fish predator. Ecology 57:751-761.

Stenseth, N. C. 1980. Spatial heterogeneity and population stability: some evolutionary consequences. Oikos 35:165-184.

Stent, C. J., and S. Hanley. 1985. A recording echo sounder for assessing submerged aquatic plant populations in shallow lakes. Aquat. Bot. 21:377-394.

Stevenson, J. C. 1988. Comparative ecology of submersed grass beds in freshwater, esturine, and marine environments. Limnol. Oceanogr. 33:8678-893.

Stott, B., and T. O. Robson. 1970. Efficiency of grass carp (*Ctenopharyngodon idella* Val.) in controlling submerged water weeds. Nature 226:870.

Stott, B., D. G. Cross, R. E. Iszard, and T. O. Robson. 1971. Recent work on grass carp in the United Kingdom from the standpoint of its economics in controlling submerged aquatic plants. Proc. Eur. Weed Res. Counc. 3rd Int. Symp. Aquat. Weeds 197:105-116.

Strange, R. J., C. R. Berry, and C. B. Schreck. 1975. Aquatic plant control and reservoir fisheries. *in* R. H. Stroud and H. Clepper, eds. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Stuber, R. J. 1982. Habitat suitability index models: black bullhead. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.14. 25 pp.

Stuber, R. J., G. Gebhart, and O. E. Maughan. 1982a. Habitat suitability index models: bluegill. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS082/10.8. 26 pp.

____________________. 1982b. Habitat suitability index models: green sunfish. U. S. Dept. Int., Fish. Widl. Serv. FWS/OBS-82/10.15. 28 pp.

____________________. 1982c. Habitat suitability index models: largemouth bass. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.16. 32 pp.

Surber, E. W. 1961. Improving sport fishing by control of aquatic weeds. Bur. Sport Fish. Wildl. (U.S.) Circ. 128.

Sutton, D. L. 1974. Utilization of hydrilla by the white amur. Hyacinth Control. J. 12:66-70.

Sutton, D. L. 1985. Management of hydrilla with triploid grass carp. Aquaculture 7:11-16.

Sutton D. L. 1990. Comparison of two methods for evaluating growth of hydrilla in sediments collected from Lake Okeechobee. J. Aquat. Plant Manage. 28:80-83.

Summerfelt, R. C. 1975. Relationship between weather and year-class strength of largemouth bass. pages 166-174. *in* R. J. Stroud, and H. Clepper, eds. Black bass biology and management. Sport Fishing Institute, Wahington, D.C.

Terrell, J. W., and T. T. Terrell. 1975. Macrophyte control and food habitats of the grass carp in Georgia ponds. Verh. Int. Ver. Theor, Angew. Limnol. 19:2415-2420.

Terrell, T. T. 1975. The impact of macrophyte control by the white amur (*Ctenopharyngodon idella*). Verh. Int. Ver. Theor, Angew. Limnol. 19:2510-2514.

Tester, A. L. 1930. Spawning habits of the small-mouthed black bass in Ontario waters. Trans. Am. Fisheries Soc. 60:53-59.

Thompson, T. W., and H. Hartwig. 1973. Control of watermilfoil in large Wisconsin lakes. Hyacinth Control J. 11:20-23.

Todd, B. L., and C. F. Rabeni. 1989. Movement and habitat use by stream-dwelling smallmouth bass. Trans. Am. Fisheries Soc. 118:229-242.

Trial, J. G., C. S. Wade, J. G. Stanley, and P. C. Nelson. 1983. Habitat suitability information: common shiner. U. S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.40. 22 pp.

Van Dolah, R. F. 1978. Factors regulating the distribution and population dynamics of the amphipod (*Gammarus palustris*) in an intertidal salt marsh community. Ecol. Monogr. 48:191-217.

Van, T. K., W. T. Haller, and L. A. Garrard. 1978. The effort of day length and temperature on hydrella growth and tuber production. J. Aquat. Plant Manage. 16:57-59.

Van Zon, J. C., J. W. Van Der Zweerde, and B. J. Hoogers. 1978. The grass carp, its effects and side effects. 4th Int. Symp. Biol. Control Aquat. Weeds.

Vince, S., I. Valiela, N. Backus, and J. M. Teal. 1976. Predation by the salt marsh killifish *Fundulus heteroclitus* L. in relation to prey size and habitat structure: consequences for prey distribution and abundance. J. Exp. Marine Biol. and Ecol. 23:255-266.

Vogele, L. E., and W. C. Rainwater. 1975. Use of brush shelters as cover by spawning black basses (*Micropterus*) in Bull Shoals reservoir. Trans. Am. Fisheries Soc. 2:264-269.

Von Geldern, C. E., Jr. 1971. Abundance and distribution of fingerling largemouth bass, *Micropterus salmoides*, as determined by electrofishing at Lake Nacimiento, California. Calif. Fish Game 57:228-245.

Walters, D. A., W. E. Lynch, Jr., and D. L. Johnson. 1991. How depth and interstice size of artificial structures influence fish attraction. NAJMDP 11:319-329.

Ware, D. M. 1973. Risk of epibenthic prey to predation by rainbow trout (*Salmo gairdneri*) J. Fish. Res. Board Can. 30:787-797.

Ware, F. J., R. D. Gasaway, R. A. Martz, and T. F. Drad. 1976. Investigation of herbivorous fishes in Florida. pages 79-84 *in* Symposium on water quality management through biological control. Rep. ENV-07-75-1. Univ. Fla., Gainesville.

Ware, F. J., and R. D. Gasaway. 1977. Effects of grass carp on native fish populations in two Florida lakes. Proc. Ann. Conf. Southeast Assoc. Game Fish Comm. 30:324-335.

Watkins, C. E. II, J. V. Shireman, and W. T. Haller. 1983. The influence of aquatic vegetation upon zooplankton and benthic macroinvertebrates in Orange Lake, Florida. J. Aquat. Plant Manage. 21:78-83.

Watson, J. E. 1955. The Maine smallmouth. Maine Dept. Inland Fisheries and Game, 1-31.

Wegener, W., D. Holcomb, and V. Williams. 1973. Sampling shallow water fish populations using the Wegener ring. Proc. 27th Southeastern Assoc. Game & Fish Commission. 663-673 pp.

Werner, E. E., and D. J. Hall. 1979. Foraging efficiency and habitat switching in competing sunfishes. Ecology 60:256-264.

Werner, E. E., and J. F. Gilliam. 1984. The ontogenetic niches and species interactions in size-structured populations. Ann. Rev. Ecol. 15:393-425.

Werner, E. E., D. J. Hall, and M. D. Werner. 1978. Littoral zone fish communities of two Florida lakes and a comparison with Michigan lakes. Environ. Biol. Fishes 3:163-172.

Werner, E. E., D. J. Hall, D. R. Laughlin, D. J. Wagner, L. A. Wilsmann, and F.C. Funk. 1977. Habitat partitioning in a freshwater fish community. J. Fish. Res. Board Can. 34:360-370.

Wetzel, R. G., and R. A. Hough. 1973. Productivity and role of aquatic macrophytes in lakes: an assessment. Pol. Arch. Hydrobiol. 20:9-19.

Whitfield, A. K. 1984. The effects of prolonged aquatic macrophyte senescence on the biology of the dominant fish species in a Southern African coastal lake. Estuarine Coastal Shelf Sci. 18:315-329.

Whittier, T. R. , R. M. Huges, and D. P. Larsen. 1988. The correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon. Can. J. Fish. Aquat. Sci. 45:1264-1278.

Whittier, T. R., and S. Paulsen 1992. Surface water component of the environmental assessment program: an overview. J. Aquat. Ecosys. Health 1:13-20.

Wildhaber, M. L., and L. B. Crowder. 1991. Mechanisms of patch choice by bluegills (*Lepomis macrochirus*) foraging in a variable environment. Copia 2:445-460.

Wiley, I. 1978. Environmental effects of mechanical harvesting. J. Aquat. Plant Manage. 16:14-20.

Wiley, M. J., R. W. Gorden, S. W. Waite, and T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. NAJMDP 4:111-119.

Williamson, K. L., and P. C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: gizzard shad. U. S. Dept. Int., Fish Widl. Serv. Biol. Rept. 82(10.112). 33 pp.

Wohlschlag, D. E. 1950. Vegetation and invertebrate life in a marl lake. Indiana Study Lakes Streams 3:321-372.

Zubik, R. J., and J. J. Fraley. 1988. Comparison of snorkel and mark-recapture estimates for trout populations in large streams. NAJMDP 8:58-62.

Table 1
Different Approaches in Habitat Classification

Criteria Used for Classification	Reference
Regional Level Classification	
Assemblage characteristics	Hawkes, Miller, and Layher (1986) Hughes et al. (1986) Larson, Johnson, and Lynch (1986) Rohm, Giese, and Bennett (1987)
Ecosystem characteristics	Bailey (1983) Whittier, Huges, and Larsen (1988)
Regional water quality	Heiskary, Wilson, and Larsen (1987)
Stream characteristics	Lyons (1989) Pflieger, Schene, and Haverland (1981)
Stream hydrology and geology	Fausch, Hawkes, and Parsons (1988) Hocutt and Wiley (1986)
Macro-Level Classification	
Biomass and standing crop	Maceina and Shireman (1980) Maceina et al. (1984) Pine, Anderson, and Hung (1989) Schloesser and Manny (1984) Shireman and Maceina (1979) Sliger et al. (1990) Duarte (1987)
Percent of plant cover	Canfield et al. (1990) Durocher, Provine, and Kraai (1984) Edwards (1983) Edwards and Twomey (1982a, 1982b) Edwards et al. (1982a) Edwards, Gebhart, and Maughan (1983) Hamilton and Nelson (1984) Inskip (1982) Krieger, Terrell, and Nelson (1983) Maceina and Shireman (1980) McMahon and Terrell (1982) McMahon, Terrell, and Nelson (1984) Stuber (1982) Stuber, Gebhart, and Maughan (1982a,b,c) Trial et al. (1983) Raleigh et al. (1984) Raleigh, Zuckerman, and Nelson (1986) Williamson and Nelson (1985)
Plant abundance	Jennings, Dewey, and Voh (1991) Lukens (1967) Nichols et al. (1988)
Plant distribution	Harvey, Patterson, Pickett (1988) Rybicki et al. (1987) Scheffer, Deredelijkheid, and Noppert (1992) Shireman and Maceina (1979) Stent and Hanley (1985)
Plant species composition and water quality	Canfield et al. (1983) Jackson and Charles (1988)

(Continued)

Table 1 (Concluded)

Criteria Used for Classification	Reference
Macro-Level Classification (Continued)	
Stream characteristics and hydrology	Hamilton and Nelson (1984)
Submersed vegetation and sediment type	Barko et al. (1982) Modde, Ford, and Parsons (1991)
Micro-Level Classification	
Dominant species	Scheffer, Achterberg, and Beltman (1984)
Emergent versus submergent vegetation	Jackson and Charles (1988) Lodge (1985) Morgan, Killgore, and Douglas (1988)
Liht intensity and shade	Helfman (1979, 1981) Johnson, Beaumier, and Lynch (1988) Lynch and Johnson (1989)
Plant density	Anderson (1984) Downing and Anderson (1985) Killgore, Morgan, and Rybicki (1989) Petrell, Bagnall, and Smerage (1991) Savino and Stein (1982)
Plant strata	Engel (1988) Morin and Kimball (1984)
Species richness	Poe et al. (1986)
Submergent versus emergent and floating	Holland and Huston (1984) *Schramm, Jirka, and Hoyer* (1987)
Substrate and interstice size	Bain, Finn, and Booke (1985a, 1985b) Johnson, Beaumier, and Lynch (1988)
Vegetation distance from shore and depth	Cook and Bergersen (1988)
Vegetated versus nonvegetated areas and depths	Gregory and Powles (1985) Layzer and Clady (1987) Hoover, Killgore, and Morgan (1988) Miller et al. (1989) Mittelbach (1988) Paller (1987) Todd and Rabeni (1989) Watkins, Shireman, and Haller (1983) Werner et al. (1977) Whitfield (1984)

Table 2
Optimum Vegetation Cover for Selected Upper Mississippi River Fishes[1]

Species	Cover, %	Reference
Gizzard shad	>30	Williamson and Nelson (1985)
Rainbow trout	>22[2]	Raleigh et al. (1984)
Brown trout	>35[2]	Raleigh, Zuckerman, and Nelson (1986)
Brook trout	>25[2]	Raleigh (1982)
Northern pike	>80	Inskip (1982)
Common carp	30-55	Edwards and Twomey (1982a)
Common shiner	20-70	Trial et al. (1983)
Creek chub	>30	McMahon (1982)
Smallmouth buffalo	>30	Edwards and Twomey (1982b)
Bigmouth buffalo	25-75	Edwards (1983)
Black bullhead	25-30	Stuber (1982)
Channel catfish	>30	McMahon and Terrell (1982)
White bass	25	Hamilton and Nelson (1984)
Green sunfish	35-80[2]	Stuber, Gebhart, and Maughan (1982b)
Warmouth	>45[2]	McMahon, Terrell, and Nelson (1984)
Bluegill	15-30	Stuber, Gebhart, and Maughan (1982a)
Smallmouth bass	25-50[2]	Edwards, Gebhart, and Maughan (1983)
Largemouth bass	40-60[2]	Stuber, Gebhart, and Maughan (1982c)
White crappie	25-80[2]	Edwards et al. (1982b)
Black crappie	25-85[2]	Edwards et al. (1982a)
Yellow perch	25-50[2]	Krieger, Terrell, and Nelson (1983)
Walleye	25-45[2]	McMahon, Terrell, and Nelson (1984)

[1] Table has been adapted from Janecek (1988).
[2] These fish may use other forms of cover in addition to vegetation. The values given are for all cover combined.

Table 3
Methods Used to Quantify Plants and Fishes in or Near Vegetated Habitats

Method	Reference
Plants	
Aerial photography	Berry et al. (1974) Durocher, Provine, and Kraai (1984) Lukens (1967) Martin et al. (1986) Jennings, Dewey, and Voh (1991)
Automated system	Harvey, Patterson, Pickett (1988)
Direct plant measurements	Petrell, Bagnall, and Smerage (1991) Pine, Anderson, and Hung (1989)
Divers	Downing and Anderson (1985) Engel (1988) Machena and Kautsky (1988) Whitfield (1984)
Fathometer	Duarte (1987) Maceina et al. (1984) Maceina and Shireman (1980) Shireman and Maceina (1979) Stent and Hanley (1985)
Line transect (boat)	Jackson and Charles (1988) Schloesser and Manny (1984)
Plant removal	Killgore, Morgan, and Rybicki (1989) Canfield et al. (1990) Holland and Huston (1984) Morin and Kimball (1984) Schramm, Jurka, and Hoyer (1987) Poe et al. (1986) Scheffer, Achterberg, and Beltman (1984) Nichols, Schloesser, and Geis (1988) Sliger et al. (1990)
Fishes	
Combination of shocker and net	Hoover, Killgore, and Morgan (1988) Killgore, Morgan, and Rybicki (1989)
Divers	Dibble (1991) Goldstein (1978) Keast and Harker (1977) Northcote and Wilkie (1963) Rodgers et al. (1992) Slaney and Martin (1987) Zubik and Fraley (1988)
Drop/throw nets	Barnett (1973) Freeman, Greening, and Oliver (1984) Wegener, Holcomb, and Williams (1973)
Stationary nets	Meador and Bulak (1987) Whitfield (1984)

(Continued)

Table 3 (Concluded)	
Method	**Reference**
	Fishes (Continued)
Explosives	Averett and Stubbs (1966) Bayley and Austen (1988) Bass and Hilt (1984) Ferguson (1962) Layher and Maughan (1984) Metzger and Shafland (1986)
Grid shocker	Bain, Finn, and Booke (1985a)
Hose pump/net	Paller (1987)
Light and minnow trap	Gregory and Powles (1985) Layzer and Clady (1987)
Popnets	Serafy, Harrell, and Stevenson (1988) Dewey, Holland-Bartels, and Zigler (1989) Espegrin and Bergersen (1990) Morgan, Kilgore, and Douglas (1988)
Radio telemetry	Cook and Bergersen (1988) Todd and Rabeni (1989)
Rotenone	Durocher, Provine, and Kraai (1984)
Seine	Freeman, Greening, and Oliver (1984) Holland and Huston (1984)
Seine/angling	Mittelbach (1984)
Shocker	Engel (1988)
Shore observations	Savino and Stein (1982)

Table 4
Topical Emphasis of Plant Control Studies

Topics	Reference
Angler-oriented plant control and sport fisheries	Berry et al. (1975) Colle (1982) Surber (1961) Wiley et al. (1984)
Comparison of bio/chemical control	Buck, Baur, and Rose (1975) Hestand and Carter (1978) Osborne, Richard, and Small (1983) Shireman and Haller (1983)
Comparison of chem/bio/mechanical control	Shireman et al. (1984)
Effects on fish by plant removal	Bailey (1978) Bettoli (1987) Bettoli, Morris, and Noble (1991) Colle, Caiteux, and Shirman (1989) Mikol (1985) Ware et al. (1976)
Effects on ichthyofauna and macrophytic insects	Haag and Buckingham (1991) Krzywosz, Krzywosz, and Radziej (1980)
Efficiency of plant control and economics	Osborne (1985) Koegal, Livermore, and Bruhn (1977) Shireman, Colle, and Canfield (1986) Singh et al. (1969) Stott and Robson (1970) Stott et al. (1971)
Environmental effects by chemical control	Gallagher (1970) Hinkle (1985)
Environmental effects of control by grass carp	Bailey (1972, 1975) Bain and Boltz (1992) Beach et al. (1976) Bettoli, Noble, and Betsill (1992) Shireman and Maceina (1981) Thompson and Hartwig (1973) Van Zon, Van Der Zweerde, and Hoogers (1978)
Plant control by grass carp	Avault (1965a, 1965b) Klussmann (1988) Pine, Anderson, and Hung (1990) Rowe (1984) Sutton (1985) Ware et al. (1976)
Plant control and control programs	Gangstad (1971) Opuszynski (1972) Reinert, Hinman, and Rodgers (1988)
Plant control and restructuring littoral zones	Dawson, Castellano, and Ladle (1978) Engel (1984) Hestand and Carter (1977)
Plant control with fertilizers	Smith and Swingle (1941)
Plant control by water level manipulation	Hestand et al. (1973) Lantz et al. (1964)
Plant control by mechanics	McGehee (1979)
Water quality and plant control	Blackburn (1975) Canfield, Maceina, and Shireman (1983) Shireman et al. (1985) Wiley (1978)

Table 5
List of Participants of the Workshop Held in New Orleans, Louisiana, June 16-17, 1992

Mark Bain New York Cooperative Fish and Wildlife Research Unit Fernow Hall Cornell University Ithaca, New York 14853-3001 (607) 255-2840	Donny Lowrey Aquatic Biology Department Tennessee Valley Authority Mussel Shoals, Alabama 45660-1010 (205) 386-2729
David Bennet Department of Fisheries and Wildlife Resources University of Idaho Moscow, Idaho 83843 (208) 885-6337	Mike Maceina Department of Fisheries 203 Swingle Hall Auburn University, Alabama 36849 (205) 844-9319
Eric Dibble Department of Zoology University of Arkansas Fayetteville, Arkansas 72701 (501) 575-5349	Ray Morgan Appalachian Environmental Laboratory Gunter Hall University of Maryland Frostburg, Maryland 21532 (301) 689-3115
Lewis Decell CEWES-EP-L 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3494	Jim Morrow CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-2973
Gary Dick Lewisville Aquatic Ecosystem Research Facility RR 3, Box 446 Lewisville, Texas 75056-9720	Brian Murphy Department of Fisheries and Wildlife Sciences Texas A&M University College Station, Texas 77843 (409) 845-5777
Bob Gunkel CEWES-EP-L 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3722	Barry Payne CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3837
Jan Jeffrey Hoover CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3996	Bill Pearson Water Resources Laboratory University of Louisville Louisville, Kentucky 40292 (502) 588-6731
Mark Hoyer Department of Fisheries and Aquaculture 7922 N.W. 71st Street University of Florida Gainesville, Florida 32606-0300 (904) 392-9617	Tom Pellett Department of Natural Resources Research Center 1350 Femrite Drive Madison, Wisconsin 53716 (608) 221-6336
Jack Killgore CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3397	Bill Richardson National Fisheries Research Center P.O. Box 818 La Crosse, Wisconsin 54602 (608) 783-6451
Phil Kirk CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3060	Bill Rushing Office, Chief of Engineers Casimir Pulaski Bldg. Washington, D.C. 20314-1000 (202) 272-1842

(Continued)

Table 5 (Concluded)

Larry Sanders CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-2976	Mike Stewart CEWES-EN-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-2606
Craig Smith CEWES-ES-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-4246	Ed Theriot CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-2678

Table 6
List of Attendees for the Workshop Held in Seattle, Washington, in July 1992

Lewis Decell CEWES-EP-L 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3722	Herb Nelson CENCS-OP 1421 USPO & Custom House 180 East Kellogg Blvd. St. Paul, Minnesota 55101-1479
Bob Gunkel CEWES-EP-L 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3722	Bob Rawson CENPS-OP P.O. Box C-3755 Seattle, Washington 98124-2255 (206) 764-3440
Jan Jeffrey Hoover CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3996	Bill Zattau CESAJ-OP P.O. Box 4970 Jacksonville, Florida 32232-0019 (904) 232-2218
Jack Killgore CEWES-ER-A 3909 Halls Ferry Road Vicksburg, Mississippi 39180-6199 (601) 634-3397	

Table 7
Funding Sequence for the Fish/Plant Interaction Technology Area

Work Unit	FY 94	FY 95	FY 96	FY 97	FY 98	FY 99
1. Classification of Aquatic Plant Habitats for Fish	—	—				
2. Fish Distribution, Diversity, and Abundance in Vegetated Habitats	—	—	—	—		
3. Reproduction of Fish in Aquatic Plant Habitats	—	—	—	—		
4. Food Web Interactions	—	—	—	—		
5. Growth and Condition of Fishes	—	—	—	—		
6. Strategies for Fisheries Management in Vegetated Waters					—	—

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1993

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Relationships Between Fish and Aquatic Plants: A Plan of Study

5. FUNDING NUMBERS
WU 32806

6. AUTHOR(S)
K. Jack Killgore, Eric D. Dibble, Jan Jeffery Hoover

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U S. Army Engineer Waterways Experiment Station
Environmental Laboratoy
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper A-93-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers, Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes a proposed new technology area in the Aquatic Plant Control Research Program on fish/plant interactions. A plan of study (POS) is presented based on a comprehensive literature review of relationships between fish and aquatic plants, and input from two workshops held with State, Federal, and university researchers. The POS discusses the need for future research according to deficiencies in the literature and serves as a basis for prioritizing and designing studies on fish/plant interactions in different geographic regions of the United States.

The purpose of the first two work units (Classification of Aquatic Plant Habitats for Fish; and Fish Distribution, Diversity, and Abundance in Vegetated Habitats) is to describe species composition and abundance of fishes associated with specific aquatic plant habitats. Once the habitat classification is completed, studies will be initiated to evaluate why fishes use specific plant habitats. This question addresses functional use of habitats by fishes and will include work units on reproduction, feeding, and growth. The functional value of plants to fishes is an essential element in understanding the complex interactions of biotic and abiotic factors that regulate population maintenance and community structure of fishes. The last work unit on management strategies will interrelate the results of the

(Continued)

14. SUBJECT TERMS

Fish habitat	Plant effects
Habitat classification	Sampling strategies
Management goals	

15. NUMBER OF PAGES
64

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

descriptive and functional studies to determine how aquatic plants should be managed for fish. Demonstration sites will be selected, and different management strategies will be applied. The results of the demonstration studies will be used to produce the technology transfer products that Corps of Engineers Districts can use to simulate and predict the outcome of different plant management strategies on fish.